Robot-assisted Procedures in General Surgery: Cholecystectomy, Inguinal and Ventral Hernia Repairs

June 2020

Prepared for:
Department of Veterans Affairs
Veterans Health Administration
Health Services Research & Development Service
Washington, DC 20420

Prepared by:
Evidence Synthesis Program (ESP) Center
West Los Angeles VA Medical Center
Los Angeles, CA
Paul G. Shekelle, MD, PhD, Director

Authors:

Principal Investigators:
Melinda Maggard-Gibbons, MD
Paul G. Shekelle, MD, PhD

Co-Investigators:
Mark Girgis, MD
Linda Ye, MD
Rivfka Shenoy, MD
Michael Mederos, MD
Christopher P. Childers, MD, PhD
Amber Tang, BA

Research Associates:
Selene Mak, PhD, MPH
Meron Begashaw, MPH
Marika S. Booth, MS

VA
U.S. Department of Veterans Affairs
Veterans Health Administration
Health Services Research & Development Service

PREFACE

The VA Evidence Synthesis Program (ESP) was established in 2007 to provide timely and accurate syntheses of targeted healthcare topics of importance to clinicians, managers, and policymakers as they work to improve the health and healthcare of Veterans. These reports help:

- Develop clinical policies informed by evidence;
- Implement effective services to improve patient outcomes and to support VA clinical practice guidelines and performance measures; and
- Set the direction for future research to address gaps in clinical knowledge.

The program is comprised of 4 ESP Centers across the US and a Coordinating Center located in Portland, Oregon. Center Directors are VA clinicians and recognized leaders in the field of evidence synthesis with close ties to the AHRQ Evidence-based Practice Center Program and Cochrane Collaboration. The Coordinating Center was created to manage program operations, ensure methodological consistency and quality of products, and interface with stakeholders. To ensure responsiveness to the needs of decision-makers, the program is governed by a Steering Committee comprised of health system leadership and researchers. The program solicits nominations for review topics several times a year via the program website.

Comments on this evidence report are welcome and can be sent to Nicole Floyd, Deputy Director, ESP Coordinating Center at Nicole.Floyd@va.gov.

Recommended citation: Maggard-Gibbons M, Girgis M, Ye L, Shenoy R, Mederos M, Childers CP, Tang A, Mak SS, Begashaw M, Booth MS, Shekelle PG, Robot-Assisted Procedures in General Surgery: Cholecystectomy, Inguinal and Ventral Hernia Repairs. Los Angeles: Evidence Synthesis Program, Health Services Research and Development Service, Office of Research and Development, Department of Veterans Affairs. VA ESP Project #05-226; 2020. Available at: https://www.hsrd.research.va.gov/publications/esp/reports.cfm.

This report is based on research conducted by the Evidence Synthesis Program (ESP) Center located at the **West Los Angeles VA Medical Center, Los Angeles, CA**, funded by the Department of Veterans Affairs, Veterans Health Administration, Health Services Research and Development. The findings and conclusions in this document are those of the author(s) who are responsible for its contents; the findings and conclusions do not necessarily represent the views of the Department of Veterans Affairs or the United States government. Therefore, no statement in this article should be construed as an official position of the Department of Veterans Affairs. No investigators have any affiliations or financial involvement (*eg*, employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties) that conflict with material presented in the report.

ACKNOWLEDGMENTS

This topic was developed in response to a nomination by Dr. Mark Wilson, National Director of Surgery, and Dr. William Gunnar, Executive Director, National Center for Patient Safety and former National Director of Surgery. The scope was further developed with input from the topic nominators (*ie*, Operational Partners), the ESP Coordinating Center, the review team, and the technical expert panel (TEP).

In designing the study questions and methodology at the outset of this report, the ESP consulted several technical and content experts. Broad expertise and perspectives were sought. Divergent and conflicting opinions are common and perceived as healthy scientific discourse that results in a thoughtful, relevant systematic review. Therefore, in the end, study questions, design, methodologic approaches, and/or conclusions do not necessarily represent the views of individual technical and content experts.

The authors gratefully acknowledge Roberta Shanman, Jon Bergman, and the following individuals for their contributions to this project:

Operational Partners

Operational partners are system-level stakeholders who have requested the report to inform decision-making. They recommend Technical Expert Panel (TEP) participants; assure VA relevance; help develop and approve final project scope and timeframe for completion; provide feedback on draft report; and provide consultation on strategies for dissemination of the report to field and relevant groups.

Mark Wilson, MD, PhD
National Director of Surgery
Department of Veterans Affairs

William Gunnar, MD
Executive Director, National Center for Patient Safety
Former National Director of Surgery
Department of Veterans Affairs

Technical Expert Panel (TEP)

To ensure robust, scientifically relevant work, the TEP guides topic refinement; provides input on key questions and eligibility criteria, advising on substantive issues or possibly overlooked areas of research; assures VA relevance; and provides feedback on work in progress. TEP members are listed below:

Bryanna Emr, MD
General Surgeon, Clinical Assistant Professor, University of Pittsburgh and VA Pittsburgh Healthcare System

Timothy Frankel, MD
Assistant Professor, General Surgery and Surgical Oncology, University of Michigan Hospitals-Michigan Medicine and Veterans *Affairs Ann Arbor Healthcare System*

Tomas Heimann, MD
Professor of Surgery, Colorectal Surgeon, Mount Sinai Hospital, New York, Chief of Surgery at James J. Peters VA Medical Center in New York, an affiliate of the Mount Sinai School of Medicine.

Frederick Luchette, MD
Chief of Surgical Service Line, Edward Hines Jr., VA Hospital; Professor of Surgery, Department of Surgery Stritch School of Medicine, Loyola University of Chicago

Peer Reviewers

The Coordinating Center sought input from external peer reviewers to review the draft report and provide feedback on the objectives, scope, methods used, perception of bias, and omitted evidence. Peer reviewers must disclose any relevant financial or non-financial conflicts of interest. Because of their unique clinical or content expertise, individuals with potential conflicts may be retained. The Coordinating Center and the ESP Center work to balance, manage, or mitigate any potential nonfinancial conflicts of interest identified.

EXECUTIVE SUMMARY

INTRODUCTION

General surgery procedures make up a large volume of operations performed in the US. For example there are approximately 1 million cholecystectomies and 800,000 ventral and inguinal hernia cases performed each year. Within this field we are experiencing dramatic recent growth in the number of robot-assisted cases. Questions about the utility of robot-assisted surgery as compared to laparoscopic and open surgery persist. In particular, does the use of the robot translate to better or similar clinical outcomes for patients? Are operating room times and length of stay comparable or improved with use of robot versus laparoscopic or open techniques? And what are costs of robot-assisted surgery and are they justified? Yet there is no consensus or guidelines on when to use which surgical approach and decisions are left up to individual practitioners or hospital leadership. To help clinicians, patients, and policymakers better assess the appropriateness of robot-assisted compared to other surgical approaches, we were asked to conduct a systematic review of the literature on 3 of the most common general surgery operations: cholecystectomy, inguinal hernia repair, and incisional hernia repair.

METHODS

This topic was developed in response to a nomination by Dr. Mark Wilson, National Director of Surgery, and Dr. William Gunnar, Executive Director, National Center for Patient Safety and former National Director of Surgery. Key questions were then developed with input from the topic nominator, the ESP coordinating center, the review team, and the technical expert panel (TEP).

The Key Questions are:

KQ1A: What is the clinical effectiveness of robot-assisted surgery compared to conventional laparoscopic surgery for cholecystectomy?

KQ2A: What is the cost-effectiveness of robot-assisted surgery compared to conventional laparoscopic surgery for cholecystectomy?

KQ1B: What is the clinical effectiveness of robot-assisted surgery compared to conventional laparoscopic or open surgery for inguinal hernia repair?

KQ2B: What is the cost-effectiveness of robot-assisted surgery compared to conventional laparoscopic or open surgery for inguinal hernia repair?

KQ1C: What is the clinical effectiveness of robot-assisted surgery compared to conventional laparoscopic or open surgery for ventral hernia surgery?

KQ2C: What is the cost-effectiveness of robot-assisted surgery compared to conventional laparoscopic or open surgery for ventral hernia surgery?

Data Sources and Searches

We conducted separate searches for cholecystectomy, inguinal hernia repair, and ventral hernia repair. All searches included PubMed, Embase, and Cochrane (all databases) from 2010 to March 2020. For inguinal and ventral hernia repairs, Medline was also searched from 2010 to 2020.

Study Selection

Studies were included if they were randomized control trials or observational studies comparing robot-assisted surgery with either conventional laparoscopic or open surgical approaches for either of the included surgical procedures. We included all randomized controlled trials (RCTs) regardless of outcomes studied. We did not have sample size restrictions for cholecystectomy, but excluded studies with sample size <10 for inguinal and ventral hernia repairs. Specifically, each comparative arm needed to have a sample of more than 10. The cholecystectomy technique is very standard (with the exception of the number of ports used). However, both hernia repair techniques are widely variable including factors such as mesh location, size of hernia, type of sutures, use of tacks, use of sutureless mesh, etcetera, and these continue to evolve. These factors were not consistently reported. As such, we made the decision that the small studies (<10 sample size) would have the potential for substantial unmeasured bias.

We also included publications of cost-effectiveness models or cost that compared robot-assisted surgery with laparoscopic or open surgical approaches.

Data Abstraction and Quality Assessment

We abstracted data on the following: study design, patient characteristics, sample size, intraoperative outcomes, postoperative outcomes, long-term functional outcomes, duration of follow-up, and data needed for the Cochrane Risk of Bias tool or Cochrane Risk of Bias In Non-randomized Studies – of Interventions (ROBINS-I).

Data Synthesis and Analysis

Because the few RCTs were too heterogeneous, we did not conduct a meta-analysis of trials. Additionally, the observational studies were too clinically heterogeneous to support meta-analysis; hence, our synthesis is narrative. We assessed robot-assisted and laparoscopic approach for cholecystectomy, as open cholecystectomy is typically performed for cancer pathology or in the setting of significant inflammation or adhesive disease. We assessed robot-assisted, laparoscopic, and open approaches for inguinal and ventral hernia repairs. Of note, cholecystectomy (for benign disease) and most inguinal hernias are performed as outpatient surgery.

Further, since there were limited RCTs and the observational studies had considerable differences between comparative arms (within and between studies), specific considerations for each of the 3 operations was warranted, in order to lessen confounding factors. Specifically, we needed to account for variations in patient factors and surgical techniques, which could impact clinical outcomes. For example, if a robot-assisted surgery study arm had a higher number of bilateral hernias than the laparoscopic group, this could account for longer operative times or higher rate of complications. Studies that performed matching (propensity matching) in our review would account for a number of important variables but typically did not control for all relevant patient or technical factors (ie, extent of fascial closure, hernia size, etc). Of note, our research team made the following judgments to facilitate comparisons of the studies identified (which were mainly observational data).

- For cholecystectomy, we present the data by grouping studies based on the number of surgical access ports used:
    - *robot single-port compared to laparoscopic single-port or robot multi-port compared to laparoscopic multi-port;*
    - *robot single-port compared to laparoscopic multi-port;*
    - *robot compared to laparoscopic for those with unknown number of ports* (in terms of outcomes).

  We did not identify any study reporting robot multi-port to laparoscopic single-port.

- For inguinal hernia repair, we present the data by grouping studies where hernia laterality (unilateral or bilateral) was:
    - *known and at least <25% between comparative arms, or outcomes reported by laterality*;
    - *laterality not known.*

- For ventral hernia repair, we present the data by grouping studies that:
    - *attempted matching on patient, hernia or technique factors;*
    - *matching not performed.*

We used the criteria of the Grading of Recommendations Assessment, Development and Evaluation (GRADE) working group to assess the certainty of evidence across studies.

RESULTS

Results of Literature Search

For cholecystectomy, we identified 887 potentially relevant citations, of which 169 were included for abstract screening. A total of 47 publications were identified at full-text review as meeting initial inclusion criteria: RCT with cost and clinical data (n=1), RCTs with clinical data only (n=3), observational studies with cost data only (n=3), observational studies with clinical outcomes only (n=25), and observational studies with both clinical and cost data (n=15).

For inguinal hernia repair, we identified 3,319 potentially relevant citations and 9 publications recommended by experts. From these, 185 were included for abstract screening. A total of 23 publications were identified at full-text review as meeting initial inclusion criteria: RCT with clinical and cost data (n=1), observational studies with clinical outcomes only (n=18), and observational studies with both clinical and cost data (n=4).

For ventral hernia repair, we identified 3,458 potentially relevant citations and 5 publications recommended by experts. From these, 369 were included for abstract screening. A total of 22 publications were identified at full-text review as meeting initial inclusion criteria: RCT with clinical data only (n=1), observational study with cost data only (n=1), observational studies with clinical data only (n=15), and observations studies with both clinical and cost data (n=5).

Summary of Results for Key Questions

KQ1A: What is the clinical effectiveness of robot-assisted surgery compared to conventional laparoscopic surgery for cholecystectomy?

In general, operative room (OR) time was longer in patients treated with robot-assisted cholecystectomy compared to laparoscopic cholecystectomy. While not always statistically significant, data are consistent across RCTs and observational studies. There was no evidence of differences in total intraoperative complications or conversions, and most studies had point estimates close to the null value. Only 6 studies reported common bile duct injuries, and there was no difference between robot-assisted cholecystectomy and laparoscopic cholecystectomy. There was no evidence that conversion rates were different between the approaches, regardless of the port comparisons. Most studies did not demonstrate a significant difference in length of stay (LOS), postoperative complications, or surgical site infections (SSI). However, there may be a trend toward lower LOS for single-port robot-assisted cholecystectomy to single-port laparoscopic approach. Postoperative pain was reported inconsistently among the studies and did not demonstrate a pattern favoring robot-assisted or laparoscopic surgery. There may also be a trend toward a lower readmission rate for the robot-assisted approach. The rate of developing a postoperative incisional hernia may be higher in single-port robot-assisted cholecystectomy. All of the studies that demonstrated a statistically significant difference in incisional hernia rate compared single-port robot-assisted cholecystectomy to multi-port laparoscopic cholecystectomy. Studies that compared single-port robot-assisted cholecystectomy and single-port laparoscopic cholecystectomy or multi-port robot-assisted to multi-port laparoscopic-assisted did not report different rates for incisional hernias. This may be because the single-port approach with robot-assisted cholecystectomy or laparoscopic cholecystectomy involves a larger incision and has a higher risk for developing an incisional hernia.

KQ2A: What is the cost-effectiveness of robot-assisted surgery compared to conventional laparoscopic surgery for cholecystectomy?

While there are a number of studies comparing the cost-effectiveness of robot-assisted versus laparoscopic surgery for cholecystectomy, all had significant limitations, primarily surrounding the cost methodology. None were formal cost-effectiveness analysis studies. Nevertheless, there was an almost unanimous finding, including in the randomized data, that the robot-assisted approach is more expensive than the laparoscopic approach. We therefore have moderate certainty that robot-assisted surgery is more expensive than laparoscopic cholecystectomy. How much more expensive is not known with precision. The lack of cost-effectiveness studies suggests that weighing the balance between the added cost against possible benefits and risks of the robot-assisted approach is not possible

KQ1B: What is the clinical effectiveness of robot-assisted surgery compared to conventional laparoscopic or open surgery for inguinal hernia repair?

Operative room time was longer in patients treated with robot-assisted inguinal hernia repair compared to laparoscopic and open repair, particularly for unilateral repairs. There was no evidence of a difference in conversions for the 3 studies reporting conversion rates between robot-assisted and laparoscopic approaches. In terms of LOS, there may be a signal of a small benefit favoring the robot-assisted approach compared to open surgery for inpatient stays. There does not appear to be a signal of benefit with regard to SSI for the robot-assisted approach compared to laparoscopic or open surgery. There may be a small signal of benefit for lower readmissions with the robot-assisted approach for bilateral and unilateral hernia repairs as compared to open approach. Most studies demonstrated no difference among approaches when assessing complications and postoperative pain. There was no evidence of difference in hernia recurrence among all approaches.

KQ2B: What is the cost-effectiveness of robot-assisted surgery compared to conventional laparoscopic or open surgery for inguinal hernia repair?

Five studies compared costs of robot-assisted to laparoscopic or open surgery for inguinal hernia repair. All had significant limitations, primarily surrounding the cost methodology. Robot-assisted surgery was more expensive in all 5 studies as compared to laparoscopic or open inguinal hernia repair. However, we judged this evidence to be of moderate certainty. Additionally, no formal cost-effectiveness analysis was performed, and thus no definitive conclusion regarding cost can be made.

KQ1C: What is the clinical effectiveness of robot-assisted surgery compared to conventional laparoscopic or open surgery for ventral hernia repair?

Operative room time was significantly longer in robot-assisted ventral hernia repair compared to both the laparoscopic and open approaches in all but 1 of the included studies. There was no evidence of difference in intraoperative complication rate among the approaches. There is a possible trend toward decreased transfusion rate with robot-assisted surgery compared to laparoscopic and open repairs, with 1 study demonstrating a significant difference favoring robot-assisted surgery and another demonstrating no difference. Conversion rate may have a small signal of being lower with robot-assisted surgery compared to the laparoscopic approach. Robot-assisted ventral hernia repair appears to significantly decrease LOS compared to open repair; however, this difference may be less than when compared to laparoscopic repair. There is a likely decrease in postoperative complication rate following robot-assisted repair compared to both open and laparoscopic approaches based on the results of matched studies (unmatched studies do not support this trend). There may be a small signal of decreased SSI rates in the robot-assisted group as compared to the open approach. There is no evidence of difference in the following specific postoperative events: readmission, mortality, or postoperative pain rates among the surgical approaches. Finally, in terms of hernia recurrence, 1 matched study showed decreased rate as compared to laparoscopic surgery and 1 study did not. The 1 matched study for open surgery showed no difference.

KQ2C: What is the cost-effectiveness of robot-assisted surgery compared to conventional laparoscopic or open surgery for ventral hernia repair?

There are a handful of cases comparing the costs of robot-assisted to laparoscopic or open surgery for ventral hernia repair. All had significant limitations, primarily surrounding the cost methodology. However, 4 of the 6 studies reported that the robot-assisted approach was more expensive than either the laparoscopic or open approach (with large effect size) and the other 2 studies reported no difference in cost as compared to laparoscopic repair. As seen for cholecystectomy and inguinal hernia, no cost-effectiveness studies were identified and definitive conclusions cannot be made.

DISCUSSION

Key Findings and Strength of Evidence

Robot-assisted surgery for cholecystectomy, inguinal hernia repair, and ventral hernia repair is associated with longer OR times, in general, and the strength of evidence ranged from high to low, depending on the procedure. The differences are possibly related to the additional docking times needed for the robot-assisted console. Of note, there is variability with how OR time was measured across the studies. Similarly, there is a learning curve effect as surgeons become more experienced on the robot over time, which some of the studies were likely capturing and others specifically addressed. For other intraoperative events, there were small signals noted favoring less transfusions and conversions to open procedure for ventral hernia repair. However, the strength of evidence was low. For postoperative LOS, there were trends favoring each procedure: moderate certainty in evidence for ventral hernia repair, and moderate certainty for LOS for inguinal hernia repair. For inguinal and ventral hernia repairs, there are signals that some postoperative complications may be lower with the robot-assisted approach for these procedures as compared to open. Likewise, there is evidence that a number of other postoperative events are lower for ventral hernia repair – specifically, postoperative complications and SSI (as compared to open approach) – but these both had low certainty of evidence. In general, the certainty of evidence is low or very low, as there were few RCTs. Readmissions may also be lower for robot-assisted approach for cholecystectomy (low certainty of evidence).

On the crucial issues of long-term outcomes, such as recurrences or chronic pain (for the 2 types of hernia repairs), data are too sparse and imprecise to reach any conclusions. Overall, the comparator arms for these procedures were limited by differences in patient factors, hernia factors (*ie*, laterality, hernia size), and varying techniques (*ie*, type of fascial closure).

Cost studies found higher expense associated with robot-assisted surgery, which was consistently reported, but these are limited by the wide variability in the methodologies and definitions used to measure cost. Formal cost-effectiveness for these 3 procedures has not been estimated and definitive conclusions regarding the balance between benefits, risks, and cost cannot be made. If efficiencies in the robot-assisted approach improve over time (as the learning curve is achieved), this in turn may bring down some of the costs. Unfortunately, we are not aware of any robot-assisted cost data within VA, but utilization data are available and this may serve as a first step towards future research in this area.

Applicability

There were a limited number of studies specific to VA populations; 1 was on cholecystectomy, 1 was on inguinal hernia repair, and none on ventral hernia repair. As such, we are unable to make specific conclusions from VA data.

Non-VA studies account for most of our evidence. Applicability of these results to VA populations may depend on both the similarity of the patients studied to VA patients and the experience of the surgical teams using robot-assisted surgery to VA surgical team experience. However, the benefits for robot-assisted approach may still be realized despite patient-level differences (VA patient population has greater burden of comorbidities than the general population), which will need to be confirmed in future studies. Urologic surgery has been widely adopted in the VA, so this experience for the staff may translate into an easy implementation to the robot-assisted general surgery field.

Research Gaps/Future Research

Numerous research gaps are apparent. There is a need for randomized data or propensity matching that addresses patient- and technique-related factors. The variability in the use of the robot-assisted approach based on these factors currently limits the ability to compare across study arms, as variations at baseline or differences in how the operation was performed are large and may likely be responsible for realized clinical differences or lack thereof. Importantly, there are advantages of the robot-assisted approach that are clear and notable – enhanced, three-dimensional visualization, augmented dexterity and range of motion, and reduction of tremor, to name a few. The heterogeneous nature of the studies limited the ability to show how these features translate into better clinical outcomes. Studies that control for key patient factors, case complexity, technical aspects of procedures, and surgeon experience may provide insight into this overarching question. Additionally, adequate long-term follow-up for certain outcomes is greatly needed. Several areas warrant specific discussion.

Surgeon Learning Curve

The surgeon learning curve is a well-characterized surgical concept that has similarly been applied to robot-assisted surgery. As with any new platform, the need for training, practice, and experience is needed. Even open surgical procedures, such as pancreatectomy, suffer from inexperienced surgeons that require tutelage before displaying mastery of a technique. The advent of laparoscopy more than 30 years ago brought this concept more into the forefront and showed the impact of surgeon learning curves on clinical patient outcomes. Likewise, surgeon learning curve for robot-assisted cases is a multifaceted issue. Previous reviews found that the surgeon experience (*ie*, ability as a function of cases completed) is fluid as it has multiple phases and surgeons tend to add increasingly complex patient cases as they gain experience.[1] In our review, we found that 90% of the studies for robot-assisted cholecystectomy acknowledged the possibility of a learning curve; however only 5/46 provided data/assessment (and findings on OR time and incisional hernia occurrence were mixed). A learning curve impact may likely vary by procedure as well. Research assessing surgeon experience needs to include a variety of clinical outcomes, not just efficiency such as OR time. With emerging technologies, research should routinely comment on and address the potential impact the level of experience of the surgeon or surgeons played.

Resident Training

Robot-assisted surgery as an evolving technology is also changing how surgical residents are educated. Furthermore, faculty surgeons need to gain their own experience while balancing training residents. 1 recent survey of program directors by Tom et al found that a 92% of programs have residents participating in robot-assisted surgery, while 68% offer formal curriculum; 44% track residents' robot-assisted experience; and about half (55%) recognize curriculum training completion. Another study also found wide variations "in requisite components, formal credentialing, and case tracking and role of simulation training". There is also no standardized approach on how to incorporate this training based on level of trainee. Overall, there is a need to adopt a standardized training curriculum and document resident competency.

Long-term Follow-up

Our work identified a lack of high quality evidence with adequate long-term follow-up and sufficient statistical power to properly assess clinical outcomes between the operative approaches for inguinal hernia repair and ventral hernia repairs. For hernia repairs, outcomes of interest need to include recurrent hernias beyond 1 year, long-term pain, and functional status. Only 1 small RCT was found for ventral hernia repair – none for inguinal hernia repair – and the 1 RCT only reported on 1 main outcome of interest. The data we found were too limited to provide conclusions in their regard.

Cholecystectomy Research Gaps

Our review focused on the use of robot-assisted surgery for benign, elective gallbladder disease. However, there is a need for future studies on cholecystectomy for non-benign pathology and emergent cases. As the robot-assisted technique is becoming more common, certain institutions are beginning to use it for cancer cases and non-elective surgeries, which are notably more complex. Given the differences in patient populations that experience these indications and the higher rates of complications for non-elective surgeries, the results from our study may not be generalizable to these populations. In fact, the robot-assisted approach may prove to be particularly advantageous for these more complex cases. The study of differences in cancer outcomes, and morbidity, for robot-assisted versus laparoscopic and open surgery is essential. As such, future research may consider expanding this review to examine different indications for cholecystectomy.

Inguinal Hernia and Ventral Hernia Repair Research Gaps

Specifically for hernia repairs, the robot-assisted approach may offer several technical advantages. For inguinal hernias, the potential for avoiding tacks or even the need for suturing mesh (sutureless mesh) may lead to less postoperative acute and chronic pain. For ventral hernia, the robot-assisted approach with improved suturing technique can also forego placement of tacks as well as possibly decrease recurrent hernia formation. Unfortunately, these technical details were not uniformly available across the studies in our review and outcomes were typically not reported by these factors. As such, it was not possible to determine their specific roles. Additionally, baseline pain was often not reported, perioperative quality of life and pain data were sparse, and long-term data on chronic pain and recurrence were rare. Standardized reporting in future work is needed in order to sufficiently assess pain outcomes, which needs to provide guidance on reporting technical aspects of the repair and requirements for clinical outcome assessment – specific time intervals, tools for assessing pain, and amount of pain medications taken.

Ergonomics for the Surgeon

An important issue that deserves study is the impact of the robot-assisted approach on the physical stress of the surgeon performing the operation. There is a high rate of musculoskeletal disorders attributed to poor ergonomics of laparoscopic surgery as well as the open approach. There are those that claim robot-assisted surgery ergonomics are superior, which translates into decreased physical stress and workload. However, there is also growing evidence that a prolonged time sitting at the robot-assisted console adds new physical challenges as well. 2 recent studies reported physical discomfort and symptoms or poor posture in over half of surgeons. Although data is sparse, it would be a valuable area for future research. While challenging to study, the outcomes would need to be comparative, long-term (5 year plus) and would require assessing detailed quality of life, assessment of chronic physical injuries, and longevity of operating over a career.

Future Innovation in Surgical Robotics

An overwhelming number of the studies in our review used the da Vinci system from Intuitive (only 1 study used the Senhance robot). The robot-assisted field is changing soon, as a number of new robot-assisted platforms are becoming available; there are 8 with FDA approval and more pending approval. These will bring with them potentially new advantages (*eg*, improved computer optics, machine learning, and automation) and possibly new challenges (*eg*, different technology with new learning curves, unknown impact on patient outcomes). Future research will be critical to assess the differences between these technologies. With these new market forces, there is anticipation for reduced cost as well.

Conflict of Interest

It is notable that reporting bias in robot-assisted surgery research has been identified. A recent study found that author payments from Intuitive were not declared in more than half (52%) of robot-assisted surgery research, and they reported more positive findings as compared to those that did declare their conflict of interest (COI) payments. There is a need to ensure full disclosure of COI with more accountability, and journals may want to adopt standardized processes to achieve better transparency.

Costs

Lastly, the lack of well-designed comparative studies also limits evaluations of cost. There is a need for standardized approaches to assess cost, which would apply to all 3 of these robot-assisted operations (*ie*, analytics approach, consistent definitions of cost, how upfront capital was accounted for, how to adjust for training staff, *etc*). Along these lines, formal cost-effectiveness studies that weigh the benefits and risks along with cost are needed.

Conclusions

Across 3 common general surgery procedures there is evidence that OR time is longer for the robot-assisted approach, and some signals that select intraoperative and postoperative complications are more favorable with the robot-assisted approach, based on the operation. Overall, the studies were heterogeneous in terms of patient characteristics and how the operations were performed and strong conclusions cannot be made. Cost is probably higher across these procedures, but the balance between the added expense and potential gains in effectiveness are unknown, until we adopt better, standardized methods of assessment.

ABBREVIATIONS TABLE

ASA	American Society of Anesthesiologists
BMI	Body mass index
CCI	Charlson comorbidity index
Chole	Cholecystectomy
COI	Conflict of interest
Comp	Complications
dVSSC	Da Vinci single-site cholecystectomy
EBDIT	Earnings before depreciation, interest and tax
EBL	Estimated blood loss
ED	Emergency Department
Elective	Elective surgery
FDA	Food and Drug Administration
F/U	Follow-up
GRADE	Grading of recommendations assessment, development and evaluation
IOC	Intraoperative cholangiogram
Lap	Laparoscopic approach
LC	Laparoscopic cholecystectomy
LOS	Length of stay
Mesh	Repair with mesh
Narc	Narcotic use
NIS	National Inpatient Sample
OR	Operating room or operating room time (where indicated)
Preop	Preoperative
Primary	Primary hernia repair
QOL	Quality of life
RAC	Robot-assisted cholecystectomy
RAS	Robot-assisted surgery
RC	Robotic cholecystectomy
RCT	Randomized controlled trial
Recur	Recurrence
Reop	Reoperation
SILC	Single incision laparoscopic cholecystectomy
ROBINS-I	Risk of bias in non-randomized studies- of interventions
Skin-to-skin	Operating time from skin incision to skin closure
SSI	Surgical site infection
SSO	Surgical site occurrence
TAPP	Transabdominal preperitoneal inguinal *hernia repair*
TEP	Totally extra-peritoneal inguinal hernia repair
Txf	Transfusion
TR	Total recurrences
USD	United States dollar