Gasless laparoscopy versus conventional laparoscopy and laparotomy: A systematic review on the safety and efficiency

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Abstract

Background: Gasless laparoscopy (GL) emerged to overcome the clinical and financial challenges of pneumoperitoneum and is often seen as a viable option for use in resource-limited settings as a means of saving costs and resources. This study aims to systematically review the evidence available on the safety and efficiency of GL compared with conventional laparoscopy (CL) and laparotomy.

Methods: Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, Medline, Embase, Web of Science and Cochrane databases were searched. Variables of interest were determined a priori and Covidence software was used to screen studies for inclusion without demographic preference. The quality of studies was assessed using the Cochrane Risk Assessment tool.

Results: Of the 1080 studies screened, a total of 43 studies were included. Laparoscopic cholecystectomy was by far the most studied intervention in randomised studies. In these, the mean setup time for gasless and CL was 13.14 (95% CI 0.16 to 26.44) and 12.8 (95% CI 10.86 to 36.47) minutes, respectively. The mean duration of surgery for gasless and CL was 89.39 (95% CI 77.44 to 101.34) and 72.59 (95% CI 63.44 to 81.74) minutes, respectively, and the mean length of stay was 4.25 (95% CI 2.02 to 6.48) and 4.04 (95% CI 1.72 to 6.36) days, respectively. Most reported complications were haemorrhage and infection with no assessable statistical difference.

Conclusions: Although GL seems to be a feasible approach for many general surgery interventions, the observed outcomes based on safety and efficiency are not sufficient to recommend GL as an alternative to CL or laparotomy. Larger randomised trials with a low risk of bias are warranted.

Keywords

cholecystectomy, gasless laparoscopy, laparotomy, pneumoperitoneum, surgery
1 | INTRODUCTION

Around 5 billion people worldwide lack access to safe, timely and affordable surgical, obstetrics and anaesthesia care.\(^1\) Because of lack of data, it becomes difficult to estimate the burden of abdominal surgical conditions.\(^2\) It is worth noting that a Global Burden of Disease study estimates the global mortality rate due to appendicitis as 0.7, biliary and liver conditions as 1.6 and intestinal obstruction as 3.9 per 100 000 population.\(^3\) A study in India showed that 1.1% of deaths (0-69 years) are attributed to acute abdominal conditions (72 000 deaths in 2020).\(^4\) In high-income settings, these conditions are managed using diagnostic imaging or diagnostic laparoscopy. The increased utilisation of laparoscopy over laparotomy stems from several benefits such as reducing pain, reducing wound infection, promoting faster post-operative recovery and return to quality of life.\(^5\)-\(^9\) However, laparoscopic abdominal surgery is resource intensive, requiring expensive surgical equipment, extensive training, general anaesthesia and a ventilator to safely manage the abdominal insufflation.

In lower-income settings, conventional laparoscopy (CL) is often unaffordable due to expensive air-tight trocars, limited availability of carbon dioxide gas and lack of general anaesthesiologists needed for patients undergoing pneumoperitoneum and ventilator support.\(^10\) Patients may instead undergo laparotomy or go without surgery. Hence, many conditions are untreated, or undiagnosed because of the lack of diagnostic equipment and procedures. This leads to increased morbidity and mortality that could have been avoided by prompt access to resources.

In the early 1990s gasless laparoscopy (GL) was introduced in a small scale primarily in resource-limited settings, as a means to avoid the financial and clinical challenges associated with pneumoperitoneum and general anaesthesia.\(^11\) The pneumoperitoneum is avoided by mechanical elevation of the anterior abdominal wall using a planar lifting system, inflatable balloon or other means to allow an overview of the abdominal organs. Several methods such as gynaecological,\(^12\)-\(^14\) upper or lower gastrointestinal\(^15\)-\(^20\) and exploratory diagnostic procedures\(^21\) have been performed through single or multiple incisions using a gasless technique.

The technique has been described and evaluated in several small studies and safety outcomes such as peri-operative complication rates\(^22\)-\(^24\) and efficiency outcomes\(^19\),\(^25\) have been compared with conventional intervention methods.

GL has been proposed to have a variety of potential benefits. One key benefit is the lower cost compared with CL due to less expensive equipment, maintenance and anaesthesia needs\(^24\)-\(^26\) as it can be used under spinal or local anaesthesia.\(^17\),\(^27\),\(^28\) It could thereby act as a diagnostic option in resource-limited settings. Some studies have reported GL to be associated with shorter duration of hospital stay for inpatients.\(^26\),\(^29\) Others suggest that GL decreases the haemodynamic burden due to abdominal insufflation in patients with haemodynamic compromise (e.g., exploratory laparoscopy for abdominal trauma).\(^17\),\(^27\),\(^28\) Other suggested benefits are improved safety outcomes in pregnancy, reduced post-site metastasis rates and reduced contamination in some procedures.\(^30\)-\(^32\) By contrast, some authors have reported that GL may carry a risk of poor visualisation during the surgery, but suggest that there is no clinical significant difference in comparison to CL.\(^18\),\(^31\)

As GL has been developed only in the last two decades, the extent of utilisation in resource-limited settings remains limited. In addition, there have been several gasless products designed and trialled but it is not yet clear which technique or design is better and in which contexts.\(^12\),\(^17\),\(^23\),\(^24\) Besides, only a few trials have used strict criteria for evaluating patient’s eligibility for surgery and presence of comorbidities and randomisation when investigating the technique.\(^15\),\(^26\),\(^35\) Moreover, it is not clear how the introduction of the technique and training for surgeons have been managed before performing the trials to help ensure safety and efficiency of GL, which is crucial when a new technique is being introduced.\(^10\)

This systematic review aims to comprehensively examine the available literature on the safety and the efficiency of GL vs other treatment modalities such as CL or laparotomy for various procedures across different study designs.

2 | MATERIALS AND METHODS

2.1 | Study design

This systematic review is designed following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.\(^36\) The study was registered in the International Prospective Register of Systematic Reviews (PROSPERO) with registration number CRD42017078338 and the protocol of the study has been published.\(^10\)

2.2 | Search strategy

A search (both automated and manual search) across MEDLINE, Embase, Web of Science and Cochrane Central, Global Index Medicus from the World Health Organisation (WHO) and the National Institutes of Health clinical trials database was performed to identify studies and records were combined using the Boolean terms AND/OR. Covidence software (Covidence.org, Melbourne, Australia) was used to pool and manage all studies found. All duplicates were identified by the software and controlled manually. The combination search terms used in MEDLINE is shown in Table 1. Endnote X9 reference manager software (Clarivate, Philadelphia, PA) was used for reference citations.

2.3 | Study selection

The inclusion criteria for the included studies followed the population, interventions, comparator, outcomes (PICO) tool, where the
population of interest was adults aged 18 years or older without any restriction to race, gender or geography (Table 2). Studies included all procedures that were done in a hospital from 1990 and onwards published in English. All excluded studies were tracked to understand how many studies were excluded based on language (Table 3). The intervention used in this study is GL. Gasless procedures were limited to general surgical procedures or conditions, or any trial involving diagnostic laparoscopy performed for general surgical investigation. It includes any variation of gasless technology and device design, any variation of gasless technique and any variation of a gasless training program. The comparison groups were general surgery patients who had CL, laparotomy or received no interventions. All study designs were included; such as case-control, cohort and randomised controlled trials (RCTs). The main outcomes that this study investigated were the safety and efficiency of GL.

### TABLE 1  MEDLINE search strategy.

| Search number | Search terms                                                                 | Results |
|---------------|------------------------------------------------------------------------------|---------|
| 1             | (laparolift or abdolift).ab,ti.                                              | 21      |
| 2             | (gasless or non insufflative or noninsufflative or non pneumoperiton* or nonpneumoperiton*).ab,ti. | 632     |
| 3             | (abdom* adj3 lift*).ab,ti.                                                   | 307     |
| 4             | (abdominal wall adj3 (suspend* or elevat*).mp. (mp = title, abstract, original title, name of substance word, subject heading word, floating sub-heading word, keyword heading word, organism supplementary concept word, protocol supplementary concept word, rare disease supplementary concept word, unique identifier, synonyms) | 77      |
| 5             | (laparos* or laparot* or peritoneoscop* or minimally invasive).ab,ti.        | 209,927 |
| 6             | 1 or 2 or 3 or 4                                                             | 925     |
| 7             | 5 and 6                                                                      | 572     |

### TABLE 2  The population, intervention, comparator, outcomes (PICO) tool.

| Population       | All races with no geographical restrictions. Human adults of at least 18 years old will be included from both genders. |
|------------------|-----------------------------------------------------------------------------------------------------------|
| Intervention     | Gasless laparoscopy                                                                                      |
| Comparators      | Conventional laparoscopy or open laparotomy                                                               |
| Outcomes         | Safety and efficiency of gasless laparoscopy                                                             |

### TABLE 3  Inclusion and exclusion criteria.

| Inclusion criteria | Exclusion criteria |
|--------------------|--------------------|
| Articles published in English and Swedish | Non-English and non-Swedish published articles |
| Articles published on or after 1992 | Studies published before 1992 |
| Adult humans aged at least 18 years from both genders with no restrictions to race or geographic distribution | Patients less than 18 years of age |
| Any trial involving gasless laparoscopy | Non-gasless laparoscopy procedure |
| Studies looking at the safety and efficiency of gasless laparoscopy | Gasless laparoscopy used for gynaecological surgery |
| N < 10 in any arm | |

### 2.4  Data extraction and analysis

Eight reviewers participated in the overall review process, with two independent reviewers reviewing each article, and a third senior reviewer involved to discuss discrepancies. Studies were initially screened based on titles and abstracts followed by full-text screening against the inclusion criteria. Data were extracted into Microsoft Excel (Redmond, WA) and specific variables were identified to for data analysis. The Cochrane Risk-of-Bias Assessment tool was used to assess the risk of bias across studies. Risk of Bias II was used for RCTs and the Risk of Bias in Non-Randomised Studies-I (ROBINS-I) tool was used for bias risk assessment in non-randomised studies. Selection bias in studies was assessed based on description of random allocation or allocation concealment of participants. Necessary tables and figures were developed based on descriptive statistics using Microsoft Excel and STATA Statistical Software Package.

### 2.5  Data synthesis

A mixed quantitative and qualitative synthesis was performed based on the strength of evidence for the outcomes of interest with specific focus on the varieties of outcomes between both the control and intervention groups. The data synthesis included the strengths and limitations of the included studies, heterogeneity of the studies, generalisability of the results to other populations and the variety of settings and different patient outcomes. Furthermore, any alternate explanations from current literature and potential future developments were investigated and discussed.

### 3  RESULTS

The search yielded 1080 studies from all the database searches. As shown in Figure 1, 43 studies were selected for full data extraction and analysis. The variation of studies by study design, intervention used and procedures were as follows: GL was the most extensively studied procedure in patients undergoing cholecystectomies, where there were 24 RCTs and 5 cohort studies. The comparator was CL in 24 of the RCTs and 4 cohort studies, while open laparotomy (OL) was the comparator in 2 cohort gastrectomy procedures as shown in Figure 2. Cholecystectomy was the procedure that was mostly
reported as an indication for either GL, CL or OL or both (CL and OL). Because of the heterogeneity of data, a meta-analysis was deemed non-feasible in this systematic review, however descriptive statistics were used to pool data for cholecystectomies due to relative homogeneity. For all other procedures only a qualitative analysis was performed. Data extracted from all 43 included articles are shown in Table 4.15,16,19,28,29,33,39–74

The main outcomes of the study examined both the efficiency and safety of GL in comparison to other interventions. Efficiency is reported as the mean setup time (minutes) of the patient for the operation, mean duration of the operation (minutes) and the total length of stay in the hospital (days) for those undergoing cholecystectomies across the 24 RCTs.

3.1 | Efficiency

In patients undergoing cholecystectomies, the mean setup time was 13.14 min (95% CI = 0.16 to 26.44) for GL from RCT studies reporting a total of 123 patients and 12.8 min (95% CI = 10.86 to 36.47 min) for CL from RCT studies reporting a total of 125 patients. The mean duration of operation for GL was 89.39 min (95% CI 77.44 to 101.34) from RCT studies reporting a total 614 patients, while it was 72.59 min (95% CI 63.44 to 81.74) for CL from RCT studies reporting a total of 633 patients (Figure 3A).

In patients undergoing GL, the mean length of stay in hospitals was 4.25 days (95% CI 2.02 to 6.48) from RCT studies reporting a

| Total number of patients across all studies reporting the following procedures |
|-----------------------------|-----------------------------|----------------------------------|-----------------------------|
| Gasless laparoscopy          | Conventional laparoscopy    | Open laparotomy                  | Both Open and Conventional  |
| Cholecystectomy              | Others                      | Gastrectomy                      | Others                     |
| 793                          | 864                         | 103                             | 56                         |
| Cohort: 118                  | Cohort: 281                 | Cohort: 53                      | Cohort: 56                 |
| RCT: 675                     | RCT: 705                    | RCT: 50                         | RCT: 50                    |
| Case control: 35             |                             |                                 | Case control: 204          |
|                             |                             |                                 | Cohort: 65                 |

**FIGURE 1** PRISMA flowchart.

**FIGURE 2** Distribution of the total number of studies across the main interventions in comparing gasless laparoscopy with either conventional laparoscopy (CL) or open laparotomy (OL) or both. RCT, randomised controlled trial.
| Study | Safety Complication | Safety Readmission | Efficiency Length of stay (mean ± SD (p-value) in days) | Efficiency Setup time (mean ± SD (p-value) in minutes) | Efficiency Duration of operation (mean ± SD (p-value) in minutes) |
|-------|---------------------|---------------------|-----------------------------------------------------|-----------------------------------------------------|-----------------------------------------------------|
|       |                     |                     | Gasless | Conventional | Gasless | Conventional | Gasless | Conventional | Gasless | Conventional | Gasless | Conventional |
| 1. Koivusalo, et al. 1998, 39 | - Physio (increase in MAP, CVP, SPO2, PO2, core temperature, pulmonary dynamic compliance, minute volume, urine output) | 108 ± 28 min | 85 +/− 25 min | 110.8 ± 36.1 (p = 0.532) | 110.8 ± 38.1 (0.532) |
| 2. Koivusalo, et al. 1997, 40 | - Metabolic: urine NAG lower—tidal volume needed to be increased | 76 ± 29 min | 87 min ±33 min | 95.96 ± 24.1 (0.012) | 75.36 +− 25.0 (<0.012) |
| 3. Koivusalo, et al. 1996, 41 | - Haemorrhage: 35.5 ± 11.7 mL average blood loss (0.099) | 5.8 ± 1.2 (0.005) | 7.2 ± 1.2 (0.005) | 129.6 ± 36.1 (p = 0.532) | 110.8 ± 38.1 (0.532) |
| 4. Uen, et al. 2002, 54 | - Wound infection (1/48 patients) | 89.66 ± 26.2 (0.072) | 74.86 ± 27.5 (0.072) | 11.56 ± 3.8 (<0.001) | 4.16 ± 1.4 (<0.001) |
| 5. Chang, et al. 2011, 43 | - Haemodynamic instability: the mean minute volume revealed a significant decrease in value during surgery for members of the GLC group (p < 0.5) | 3.3 ± 1.3 (0.512) | 3.1 ± 1.4 (0.512) | 10.6 ± 3.5 (0.008) | 7.5 ± 5.0 (0.008) | 98.3 ± 27.2 (0.008) | 77.4 ± 27.7 (0.008) |
| 6. Vázquez-Rosales, et al. 2010, 54 | - Haemorrhage: 40.3 ± 12.1 average blood loss (0.099) | 5.8 ± 1.2 (0.005) | 7.2 ± 1.2 (0.005) | 129.6 ± 36.1 (p = 0.532) | 110.8 ± 38.1 (0.532) |
| 7. Wu, et al. 2010, 19 | - Metabolic: ETCO2 lower — | 89.66 ± 26.2 (0.072) | 74.86 ± 27.5 (0.072) | 11.56 ± 3.8 (<0.001) | 4.16 ± 1.4 (<0.001) |
| 8. Uen, et al. 2007, 42 | - Wound infection (1/48 patients) | 89.66 ± 26.2 (0.072) | 74.86 ± 27.5 (0.072) | 11.56 ± 3.8 (<0.001) | 4.16 ± 1.4 (<0.001) |

(Continues)
| Study | Complication | Readmission | All-cause mortality | Length of stay (mean ± SD (p-value) in days) | Setup time (mean ± SD (p-value) in minutes) | Duration of operation (mean ± SD (p-value) in minutes) |
|-------|--------------|-------------|---------------------|---------------------------------------------|---------------------------------------------|------------------------------------------------|
| 9. Ohta, et al. 1997 | Subcutaneous emphysema, inguinal pain, inguinal seroma, subcutaneous bleeding, small bowel obstruction, paralytic ileus and testis swelling | Haemorrhage + subcutaneous emphysema, inguinal pain, inguinal seroma, subcutaneous bleeding, small bowel obstruction, paralytic ileus, testis swelling | Yes | 6.7 ± 2.1 | 6.1 ± 1.5 | 94.7 ± 23.4 |
| 10. Nanashima, et al. 1998 | | | | 141 ± 31.5 | 125 ± 34.9 | |
| 11. Ortiz-Oshiro, et al. 2001 | | | | | | |
| 12. Vezakis, et al. 1999 | | One patient had wound infection | | 8 | 5 | 85.0 ± 11.6 |
| 13. Ninomiya, et al. 1998 | | | | 93.6 ± 11.8 | | (p > 0.05) |
| 14. Luo 2009 | Haemorrhage: 64.13 ± 163.66 (P = .63) | Haemorrhage: 62.8 ± 113.5 (P = .63) | | 7.57 ± 1.9 (6–15) P = .63 | 8.3 ± 1.9 (5–13) P = .63 | 141.83 ± 32.72 (106–200) P = .46 |
| 15. Korkmaz 2002 | 1/20 intra-abdominal abscess drained through laparotomy | 1/20 intra-abdominal abscess, drained through laparotomy | | 3.7 | 1.7 | |
| 16. Wu 2013 | Haemorrhage: 139.1 (24.7) mL | Haemorrhage: 185.8 (45.0) mL | | 18.7 ± 1.4 | 20.9 ± 1.7 | 220.6 ± 13.6 |
| 17. Cavina 1993 | Visceral perforation: CBD injury | | | 52.9 | 62.1 | |
| 18. Larsen 2001 | Haemodynamic instability: High (systolic diameter, | | | Median (range), 102 (90–210) | Median (range), 78 (45–170) | |
| Study | Safety | Efficiency |
|-------|--------|------------|
|       | Complication | Readmission | All-cause mortality | Length of stay (mean ± SD (p-value) in days) | Setup time (mean ± SD (p-value) in minutes) | Duration of operation (mean ± SD (p-value) in minutes) |
| Gasless | Conventional | Gasless | Conventional | Gasless | Conventional | Gasless | Conventional | Gasless | Conventional |
|        | MINOR | Minor: three patients with abnormal LFT, 1 with mild bile leak, wound infection, asthma attack and wound dehiscence | One patient converted from peritoneal lift to open laparotomy due to bleeding (no further details provided) | 8.6 ± 4.6 | 8.3 ± 3.9 | 13.7 ± 5.0 | 13.2 ± 5.3 | 1000 ± 46.8 | 93.4 ± 40 |
| Japanese Association of Abdominal Wall Lifting for Laparoscopic Surgery (JAAWLLS) Anonymous 1999 | 20. | 6.3 ± 2.0 | 6.6 ± 2.5 | 2200 ± 55.7 | 2569 ± 59.4 |
| Jiang 2010, | 21. | 6.0 ± 2.1 | 4.7 ± 1.0 | 50.6 ± 17.2 | 49.9 ± 19.9 |
| Kim 2002 | 22. | 61 ± 11 | 51 ± 20 | |
| Koivusalo 2008 | 23. | 50.6 ± 17.2 | 49.9 ± 19.9 | |
| Lee 2013 | 24. | 7.1 | 10.7 | 116.6 | 119.6 |
| Chen 2012 | 25. | Haemorrhage: 43.3 mL ± 59.4 mL (P < .05) | Haemorrhage: 2500 mL ± 347.9 mL (mean ± SD) | 1411 ± 52.6 (P < .05) | 2042 ± 74.3 (mean ± SD) |
| Ortiz-Oshiro 2001 | 26. | 25 (median) | 35 (median) | Median, 60 | Median, 60 |
| Larsen 2002 | 27. | 1/26 bile leakage | 1 patient | 1 (range 1-31) median | 102 | 78 |
| Larsen 2001 | 28. | Two post-operative fever (discharge after 1 and 3 days), 1 with aberrant duct—stented | 1 | 5 | 8 | 102 | 78 |

(Continues)
| Study          | Safety                                                                 | Efficiency                                                                 |
|---------------|------------------------------------------------------------------------|-----------------------------------------------------------------------------|
|               | Complication | Readmission | All-cause mortality | Length of stay (mean ± SD (p-value) in days) | Setup time (mean ± SD (p-value) in minutes) | Duration of operation (mean ± SD (p-value) in minutes) |
|               | Gasless | Conventional | Gasless | Conventional | Gasless | Conventional | Gasless | Conventional | Gasless | Conventional |
| 29. Ishikawa 2006, 64 | 2/207 Bile duct injury, 0/224 bile duct leakage | 2/224 abdominal bleeding, 23 mL ± 51–2/224 bile duct injury, 3/224 bile duct leakage 1/207 abdominal abscess (no significant differences) | | 10.4 ± 8.8 | 10.9 ± 7.0 | 105 ± 53 | 94 ± 47 |
| 30. Chou 2008, 65 | Haemorrhage: 95.63 ± 31.33 mL—wound infection: two patients | Haemorrhage: 207.22 ± 73.31 mL—wound infection: 1 patient | | 11.3 ± 1.36 | 14.39 ± 2.93 | 208.38 ± 23.21 | 206.11 ± 13.9 |
| 31. Huang 2010, 66 | Supraventricular or ventricular arrhythmia during procedure | Wound infection | | 7.4 | 8.3 | 139.4 ± 76.2 (P = .879) | 143.8 ± 65.1 (P = .879) |
| 32. Uemura 2002, 67 | Two wound infections | Increase in MAP, PAP, and minute ventilation. Haemorrhage: three patients Haemorrhage: two patients | | 48.9 hours | 47.4 hours | 5.4 ± 0.68 P ≤ .05 | 4.55 ± 0.51 P ≤ .05 | 41.8 ± 7.89 P ≤ .05 | 31.55 ± 4.25 P ≤ .05 |
| 33. Beberaolu 1999, 68 | Wound infection | Wound infection | | 3 | 3 | 50.49 ± 10.9 (range, 30–75 min) | 70.8 ± 16 (range, 40–120 min) |
| 34. Talwar 2006, 69 | Haemorrhage: three patients Haemorrhage: two patients | Two wound infections | | | | |
| 35. Anderson 2001, 70 | One omental injury (visceral perforation) | | | | | |
| 36. Egawa 2006, 71 | Visceral perforation: 2 | Visceral perforation: 3 | | | | |
| 37. Giraudi 2001, 72 | Haemorrhage: one required blood transfusion | Haemorrhage: one required blood transfusion | | 6.9 ± 2.5 | 6.3 ± 2.0 | 182.1 ± 9.21 (P < .05) | 135.1 ± 46.1 (P < .05) |
| 38. Hyodo 2012, 73 | Haemorrhage: one required blood transfusion | Haemorrhage: one required blood transfusion | | 4.36 ± 1.74 | 5.68 ± 4.43 | 70.6 ± 30.8 (P = .138) | 62.6 ± 22.0 (P = .138) |
| 39. Ge 2014, 74 | Wound infection (1/50) Intabdominal abscess 1/50 | Wound infection (2/50) Intabdominal abscess 1/50 | | 7.1 (4.5) | 16.3 (6.4) | 109.7 ± 33.5 | 131.2 ± 43.6 |
| 40. Lindgren 1997, 75 | Visceral perforation: 2 | Visceral perforation: 3 | | 102 | 86 | 9.1 | 10.4 |
total of 423 patients, while it was 4.04 days (95% CI 1.72 to 6.36) from RCT studies reporting a total of 440 patients (Figure 3B).

From non-RCT studies, such as case-controls and cohorts (10 studies), there were several non-cholecystectomies (e.g., abdominal trauma, intestinal neoplasm—wedge resection, subtotal gastrectomy, gastrointestinal stromal tumour removal, upper gastrointestinal stromal cancer, liver cystectomy, gastrectomy, colorectal lesions removal and inguinal hernia herniorrhaphy) that had a variation in the duration of operation time. For example, colorectal lesions had the highest duration of operation for studies reporting GL and both (CL and OL): 220 and 256.9 min, respectively. This was followed by gastrectomy, where studies reported a duration of operation for GL and both (CL and OL) to be 220.6 and 245.8 min, respectively. By contrast, liver cystectomies had the lowest duration of operation for GL and studies reporting both GL and OL had a duration of operation of 50.49 and 70.8 min, respectively. The remaining procedures’ duration of operation ranged between 90.8 and 143.8 min. Overall, GL had less duration of operation compared with both CL and OL except in inguinal hernia herniorrhaphy and upper gastrointestinal stromal cancer removal. The overall mean duration of operation was 152.66 min (95% CI 101.01 to 204.3) for non-RCT studies reporting a total of 217 patients undergoing both OL and CL techniques. By contrast, for GL the mean duration of operation was 135.8 min (95% CI 93.37 to 178.23) for non-RCT studies reporting a total of 235 patients (Figure 4A).

From non-RCT studies, such as case controls and cohorts (10 studies), there were several non-cholecystectomies (e.g., abdominal trauma, intestinal neoplasm—wedge resection, gastrointestinal stromal tumour removal, upper gastrointestinal stromal cancer removal, liver cystectomy, gastrectomy, colorectal lesions removal) that had a variation in the length of stay in hospitals as inpatients. Those who underwent a gastrectomy had the overall highest length of hospital stay for those who underwent GL and both OL and CL at 18.7 and 20.9 days, respectively. By contrast, those who were admitted for liver cystectomy undergoing GL and both OL and CL had the lowest length of hospital stay at 3 days for each technique. The rest of the range of lengths of hospital stay across all admissions for all techniques was between 4.5 and 10 days. GL consistently had lower length of hospital stays across all admissions. The overall mean length of hospital stay was 7.54 days (95% CI 2.78 to 12.31) for those who had GL (across 167 patients from the non-RCT studies) and for those who had both CL and OL it was 9.01 days (95% CI 3.72 to 14.31; across 155 patients from non-RCT studies; Figure 4B).

### 3.2 Safety

The safety of the surgical techniques has been structured into three main categories: surgical complications, readmissions to hospitals and all-cause mortality. There were five main complications identified as resulting from undergoing GL, CL, laparotomy or both, including wound infection, deep tissue infection, haemorrhage, haemodynamic instability and visceral injury.
Haemorrhage was the mostly reported complication in eight studies for patients undergoing GL, eight studies for patients undergoing CL, one study in OL and one study in those who had both CL and OL. This was followed by visceral injuries, where GL contributed to visceral injury in seven studies, CL in six studies and both CL and OL in two studies. Next was haemodynamic instability, which was reported in six GL studies, six CL studies, one OL study and one study in both CL and OL. Deep tissue infection was then reported in seven GL studies, four CL studies and one
Finally, wound infection was reported in seven GL studies, three CL studies and two studies in both CL and OL. Readmissions were reported equal in five studies for those who underwent GL and five studies for those who underwent CL. Only one study reported all-cause mortality in GL (Figure 5).

### 3.3 Risk-of-bias assessment

More than 50% of the RCTs reported low risk of bias as shown in Figure 6A, except in allocation concealment, which showed that around 35% of studies had a low risk of bias, and per-study risk-of-bias analysis
is shown in Figure 6B. Around 75% of non-randomised studies had a low risk of bias except around 35% of studies that showed a low risk of confounding and selection bias, as shown in Figure 7A, and the per-study risk-of-bias analysis is shown in Figure 7B.

4 | DISCUSSION

This systematic review identified 43 studies that were eligible for inclusion for assessment of the safety and efficiency of GL in comparison to CL or laparotomy or both. There were a total of 25 RCTs and 17 non-RCT studies.

Safety was assessed based on post-operative complications, readmissions and all-cause mortality. Overall post-operative complications and readmissions were very similar for GL, CL and OL across all study designs and procedures. The complications found were mainly wound and deep tissue infections, haemorrhage, haemodynamic instability and visceral injury. However, in three studies GL was associated with an increased risk of wound and deep tissue infections compared with other interventions. This is not suffice to state that there are more infections after GL compared with CL or OL; however, there may be a plausible increased risk due to the use of the retractor, Laparo-lift or the Laparo-tensor introduced through the abdominal wall during the abdominal wall lifting in GL, and this needs to be confirmed in the future.75 Gurusamy et al.75 reviewed GL only in studies on cholecystectomy until 2011, while our review has also included studies published over the last decade and for a wider span of conditions and compares GL with CL and OL, explaining partly divergent conclusions. Efficiency was assessed based on the setup time, duration of operation in minutes and length of hospital stay in days. For cholecystectomies, the setup time for surgery for GL and CL was almost the same. This may indicate that the setup time is similar for the techniques regardless of the procedure.

The RCT studies showed that in cholecystectomies, the average duration of operation for GL was 89 min compared with 73 min for CL. The prolonged duration of surgery using GL for cholecystectomies may be due to the slightly reduced surgical site exposure compared with CL. This is also reported in the study by Vezakis et al.,76 who found that intra-operative cholangiography was more successful in CL compared with GL. The inadequate exposure could be explained by the flat-topped pyramid space limited to the specific abdominal quadrant, particularly in obese and muscular patients and those with adhesions.76

In non-RCT studies, the duration of surgery was higher for those undergoing CL or OL or both for all other diseases (such as abdominal trauma, gastrectomy, tumour removal, hemia and colorectal lesions). On average, the mean length of hospital stay was higher for those undergoing CL or OL or both compared with GL across most of the diseases. If this difference is replicated in future studies, plausible contributing factors may be the negative effects of pneumoperitoneum such as an increased intraabdominal pressure and absorption of carbon...
dioxide from the peritoneal cavity, or the increased trauma of open surgery. The mechanism for pneumoperitoneum could be responsible for the cardiopulmonary effects due to the increased intra-abdominal pressure pushing the diaphragm upwards, which results in a reduction of the pulmonary function and a reduction of the venous return and stroke volume through splanchnic vasoconstriction.

The strength of this analysis is the comprehensive and critical assessment of available literature in the field on the safety and efficiency of GL, CL and OL in abdominal surgery. The quality of all papers was assessed for bias and the overall quality of the included studies was good. However, this study still posits some limitations. A meta-analysis was deemed inappropriate due to the lack of quantitative metrics and homogeneity of data. The evidence to support any firm conclusions about GL efficiency and safety are still to be awaited. Additionally, safety of GL interventions could reflect on the quality of life of the patient, a dimension not explored in any of the studies, reflecting a limitation in the studies that were included. Furthermore, the duration of the operation or length of hospital stay does not comprehensively reflect efficiency. Based on available data in reviewed literature many confounding factors, such as the complexity of the pathology being operated on, the experience of the operating surgeon and the personnel working in the operating room, the surgical technique used, the setup of the procedures or the resources of the facility, could not be explored in this analysis. Furthermore, no rigorous cost-effectiveness analysis could be performed based on available data.

FIGURE 6 (A) Cochrane risk-of-bias graph—assessment of randomised studies. Risk of bias in randomised controlled trials. Bias 1: outcomes—detection bias; bias 2: participants—performance bias; bias 3: incomplete outcome (attrition bias); bias 4: selective outcomes (reporting bias); bias 5: allocation concealment; bias 6: random sequence generation. (B) Cochrane risk-of-bias summary of all randomised studies.
CONCLUSION

GL seems to be a promising alternative to CL or OL in a variety of procedures. However, the lack of homogeneity of data precluded a comprehensive meta-analysis in this systematic review. Hence, the observed outcomes based on safety and efficiency are not sufficient to recommend GL as an alternative to CL for the admitted conditions at this time. Data for cholecystectomies do seem to show non-inferiority and as the cost of GL is likely lower, this technology should be further investigated. Going forward, larger, randomised studies with detailed perioperative, quality of life and cost data would provide stronger evidence for utilisation of the GL technique.

AUTHOR CONTRIBUTIONS

The design of the project and review was done by Haitham Shoman, Simone Sandler, Alexander Peters and David Ljungman. The drafting of the protocol was done by Haitham Shoman, Simone Sandler and Alexander Peters. All authors have contributed to the protocol editing and approval and David Ljungman has been guiding the project direction and choice of journal.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.
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