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REVIEW ARTICLE

Clinical effectiveness of gasless laparoscopic surgery for abdominal conditions: systematic review and meta-analysis

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Abstract

Background In high-income countries, laparoscopic surgery is the preferred approach for many abdominal conditions. Conventional laparoscopy is a complex intervention that is challenging to adopt and implement in low resource settings. This systematic review and meta-analysis evaluate the clinical effectiveness of gasless laparoscopy compared to conventional laparoscopy with CO_2 pneumoperitoneum and open surgery for general surgery and gynaecological procedures.

Methods A search of the MEDLINE, EMBASE, Global Health, AJOL databases and Cochrane Library was performed from inception to January 2021. All randomised (RCTs) and comparative cohort (non-RCTs) studies comparing gasless laparoscopy with open surgery or conventional laparoscopy were included. The primary outcomes were mortality, conversion rates and intraoperative complications. Secondary outcomes: operative times and length of stay. The inverse variance random-effects model was used to synthesise data.

Results 63 studies were included: 41 RCTs and 22 non-RCTs (3,620 patients). No procedure-related deaths were reported in the studies. For gasless vs conventional laparoscopy there was no difference in intraoperative complications for general RR 1.04 [CI 0.45–2.40] or gynaecological surgery RR 0.66 [0.14–3.13]. In the gasless laparoscopy group, the conversion rates for gynaecological surgery were high RR 11.72 [CI 2.26–60.87] when compared to conventional laparoscopy. For gasless vs open surgery, the operative times were longer for gasless surgery in general surgery RCT group MD (mean difference) 10 [CI 0.64, 19.36], but significantly shorter in the gynaecology RCT group MD − 18.74 [CI − 29.23, − 8.26]. For gasless laparoscopy vs open surgery non-RCT, the length of stay was shorter for gasless laparoscopy in general surgery MD − 3.94 [CI − 5.93, − 1.95] and gynaecology MD − 1.75 [CI − 2.64, − 0.86]. Overall GRADE assessment for RCTs and Non-RCTs was very low.

Conclusion Gasless laparoscopy has advantages for selective general and gynaecological procedures and may have a vital role to play in low resource settings.

Keywords Gasless laparoscopy · Abdominal wall lift · LMIC · Low resource setting · Rural surgery · Clinical effectiveness · Open surgery · General surgery · Gynaecological surgery

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Globally, general surgical and gynaecological diseases are a significant health burden [1]. Timely access to surgery is cost-effective and can make a substantial contribution to improving global health [2]. The Lancet Commission on Global Surgery has estimated that 143 million additional surgical procedures are needed in Low- and Middle-Income Countries (LMICs) each year to save lives and prevent disability [3].

According to the disease control priorities (DCP-3) on essential surgery, 9% of deaths due to acute abdominal conditions (appendicitis, gallbladder and bile duct disease, hernia, and paralytic ileus/intestinal obstruction) could have been avoided and 6.3% of Disability Adjusted Life Years (DALYs) averted per year if basic surgical care was available in LMICs [1]. The estimate is even higher for maternal and neonatal surgical conditions. Essential surgical procedures are defined as those who have large health burden, cost-effective and can be successfully treated by a surgical intervention [4].

In high-income countries, laparoscopic surgery is associated with better patient outcomes, shorter hospital stays and early return to work when compared to open surgery. These benefits are also recognised in low- and middle-income countries [5], with laparoscopic surgery associated with lower complications, particularly lower surgical site infection rates [6–8].

Although the benefits of laparoscopic surgery are well-recognised, its diffusion in low resource settings of LMICs has been slow. The process of introducing conventional laparoscopic surgery in LMICs is challenging, mainly due to limited infrastructure, resources and lack of training opportunities [9, 10]. In the last decade, due to lower implementation costs, gasless laparoscopy has become increasingly popular for emergency and elective abdominal surgery in low resource settings [4, 11, 12]. In this technique, the surgeon makes a small incision around the umbilicus and inserts a planar or a ring device. This is used to lift the abdominal wall and create the "working space" without the need to insufflate the abdomen with CO_2 gas. The remaining steps are performed in a similar fashion to conventional laparoscopic surgery.

Recent publications have demonstrated non-inferiority of gasless laparoscopy for general and gynaecological surgery with no difference in peri-operative outcomes when compared to conventional laparoscopy [13, 14]. Non-RCTs comparing gasless to open surgery have also shown favourable outcomes [15, 16]. A Cochrane review of RCTs reported outcomes of gasless as compared to conventional cholecystectomy and another review focussed on the safety of myomectomy [17, 18]. These studies were unable to draw any conclusive evidence of non-inferiority of gasless over conventional or open surgery. To our knowledge, no meta-analysis has been carried out comparing gasless laparoscopy to open surgery or conventional laparoscopy for procedures that include essential general surgical and gynaecological conditions.

Methods

Search strategy and selection criteria

A systematic review and meta-analysis were conducted and reported following the updated PRISMA guidelines 2020 (Fig. 1) [19].

The bibliographic databases MEDLINE, EMBASE, Global Health, AJOL and Cochrane Library were searched from inception to April 2020 and re-run in January 2021, with no language restrictions, for studies comparing gasless laparoscopy with conventional laparoscopy or open surgery. Additional studies were identified from previously conducted systematic reviews on gasless laparoscopy. Text words and MeSH terms for laparoscopy and minimally invasive surgery were combined with terms related to gasless techniques and excluded non-abdominal procedures using breast, prostat*, urolog*, nephr*, thoracic, endocrine or thyroid. The syntax with search terms is shown in (Supplement search strategies). De-duplication and screening were carried out on EndNote software (X 8.2).

Inclusion of the studies was a stepwise process. Two reviewers (NA and WSB) independently screened the titles and abstracts against the agreed inclusion criteria, and then extracted and selected relevant full-text records. Discrepancies were resolved through discussion at each stage by consensus. Two additional authors (AM & LB) verified the eligibility of inclusion of the studies when necessary.

Included studies compared gasless to conventional laparoscopy, open surgery or both techniques for general surgical and gynaecological conditions in humans. Only RCTs and Non-RCTs were included in the systematic review and meta-analysis. The term non-RCTs used in this review includes comparative prospective and retrospective cohort studies [20]. Case reports, case series or review articles were excluded. The conversion rate for gasless was defined as those cases which were converted to conventional laparoscopy with CO_2 pneumoperitoneum or open surgery.

Data analysis

Assessment of both methodological quality and risk of bias was performed by NA and reviewed by WSB independently. Disagreements were resolved by discussion between AM and LB. Included studies were stored on an Excel spreadsheet for data extraction. Details extracted included: study design, follow-up period, device, operated organ, comparators and sample size. The primary outcomes were mortality,

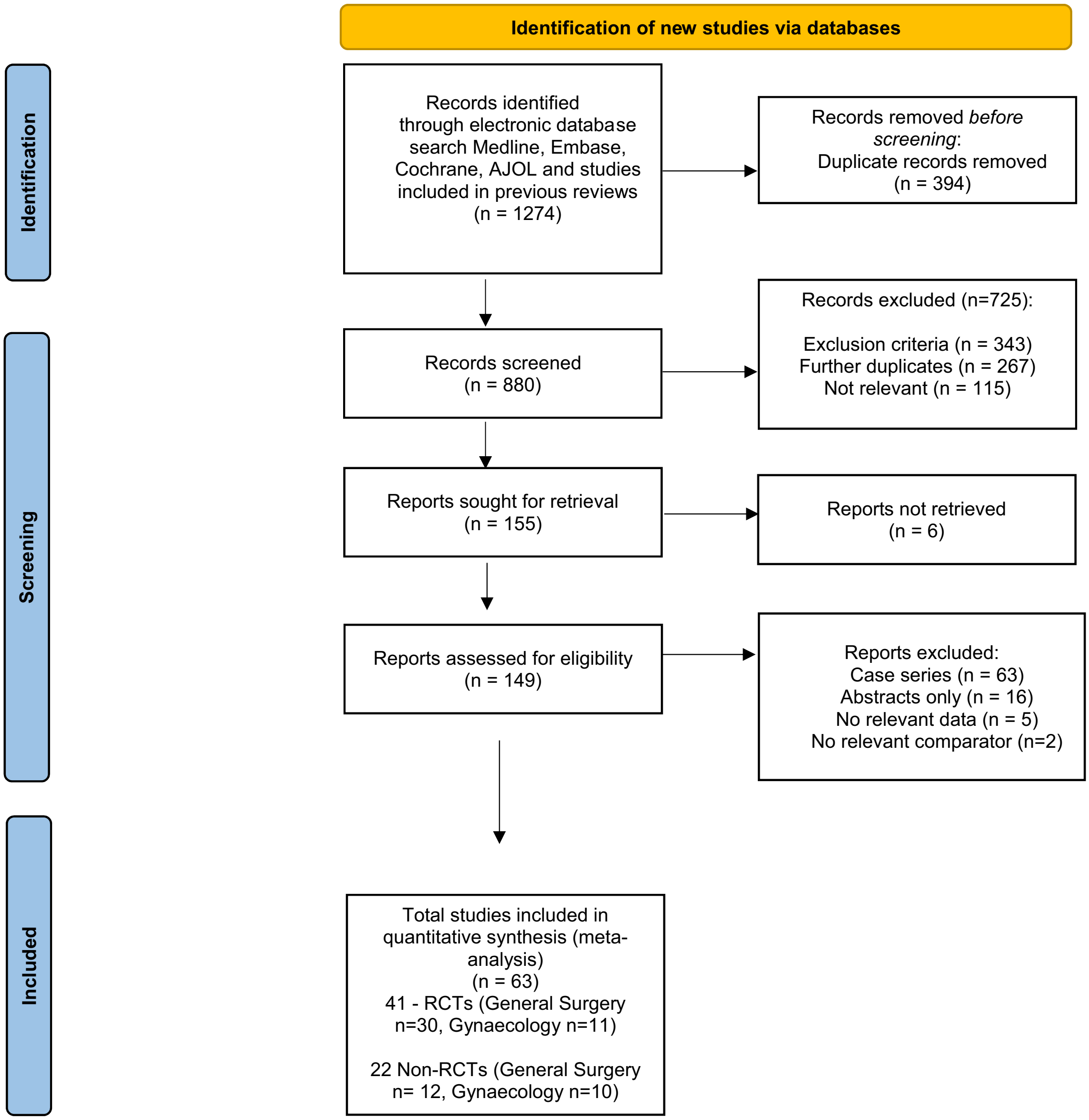

Fig. 1 PRISMA flow chart

conversion rate and intraoperative complications. Secondary outcomes were overall complications (inclusive of intraoperative complications), operative time and length of operative stay.

Risk-of-bias assessment for each outcome in randomised controlled trials (RCTs) was done using the risk of bias—2 (RoB-2) tool for six domains: randomisation process, deviation from the intended interventions, missing outcome data, measurement of the outcome, selection of the reported result and overall risk of bias [21]. The risk of bias for each outcome in the non-RCT studies was assessed with ROBINS-I tool with seven domains: confounding, selection of participants, classification of interventions, deviations from intended interventions, missing data, measurement of outcomes and selection of the reported result and overall [22].

Domain level and overall risk of bias judgements for the outcomes in RCTs were assessed as having either a low, some concerns or high risk of bias according to the RoB-2 tool. For ROBINS—I tool, results of non-RCT studies were assessed for domain level and overall risk of bias as having either low risk, moderate, severe, critical and no information. Within each study, we summarised the risk of bias for individual outcome of interest for each comparator using RoB-2 and ROBINS-I tool. Effect measures for outcomes which were 'not estimable' were excluded from risk of bias assessment. In addition, we used the GRADE assessment of the quality of evidence to summarise the primary and secondary outcomes in RCTs and non-RCT studies [23]. Within GRADE, certainty assessment for RCTs was based on the following parameters: risk of bias, Inconsistency, Indirectness and Imprecision. A summary of evidence table was compiled using GRADEpro GDT software (McMaster University, 2020) for general surgery and gynaecology RCT and non-RCT studies. The interpretation of the quality of evidence for RCT and non-RCT studies was done independently based on the effect measure and not compared to each other.

In the meta-analysis, the effect measures were estimated for each comparator using the Forest Plot. To address heterogeneity, we performed subgroup analyses for RCT and Non-RCT studies for general surgery and gynaecology procedures, for each outcome of interest. Due to assumed heterogeneity of the data, inverse variance random-effects models were used for dichotomous and continuous data, with significance set at 95% confidence interval or p-value of <0.05 as significant. We evaluated heterogeneity using I^2 statistics for between study variance for the subgroup analysis and pooled effect. For conversion rates, we used a funnel plot to assess for publication bias in the included studies.

The overall treatment effect was calculated as a weighted average of events for individual summary statistics. Measures of effect: for dichotomous data—risk ratio (RR) with a 95% confidence interval (CI) was used. Continuous data were analysed using mean difference (MD) with 95% CI. Subgroup analysis was also performed for studies included in the LMIC population groups.

Analyses were performed using Review Manager software (RevMan version 5.4; The Nordic Cochrane Centre, Copenhagen, Denmark) [24]. The study was prospectively registered on PROSPERO CRD42020173264 https://www.crd.york.ac.uk/prospero/display_record.php?RecordID=173264.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

We identified 1274 records on initial screening (Fig. 1). After removing duplicates, 880 records were screened using abstracts. At this stage, 731 studies that did not meet the inclusion criteria were excluded. Out of 155 reports sought for retrieval, 6 reports were not retrieved. Based on a full-text review of the remaining 149 studies, a further 86 studies were excluded leaving a total of 63 studies (41 RCTs and 22 non-RCT).

A total of 3,648 patients were included in the systematic review and meta-analysis. The RCTs of general surgical ($n=30$) and gynaecological procedures ($n=11$) consisted of 2263 patients (Table 1 supplement) [13, 25–64]. The majority of the general surgical procedures included in the review were cholecystectomy, appendicectomy and diagnostic laparoscopy. In the gynaecology group; adnexal procedures, myomectomies and hysterectomies were included. A detailed breakdown can be found in Supplement Tables 1 and 2.

A detailed summary of the risk of bias for RCTs using RoB—2 tool is listed in Table 3 Supplement. In the non-RCT group, there were 12 general surgery and 10 gynaecology studies, with a total of 1,385 patients (Table 2 Supplement) [14–16, 65–83]. The overall result level assessment for each outcome varied between low to high risk of bias. Complication rates were assessed at having 'some concerns' to 'high risk' of bias due to issues around randomisation process or measurement and selection of outcome domains. Conversion rates, operative time and LoS were assessed as 'low' to 'some concerns'. The summary of the risk of bias of non-RCTs according to the ROBINS-I tool is listed in Table 4 Supplement. Overall risk of bias for complication and conversation rates were assessed as 'moderate' to 'serious' due to confounding, selection of participants, measurement and selection of results domain. Overall risk of bias for operative times and LoS were reported at low to moderate.

A detailed level of evidence is summarised in GRADE assessment tables for RCTs and non-RCTs (Tables 5–8) comparing gasless to conventional laparoscopy and open surgical technique. It provides relative and absolute effect measures of the results summarised above and gives certainty of evidence for each comparator in each domain. Most studies are graded as low or very low level of evidence.

Primary outcomes

Mortality

Forty six percent (19/41) of the RCTs reported no mortality. Only 29% (12/41) of the studies reported short-term follow-up timings, apart from one study which followed up patients for a year [25]. Remaining studies did not report the duration of follow-up of the enrolled patients. In non-RCT studies, 27% reported no mortality, except one death which was reported due to malignancy 45 days post-operatively [16].

Intraoperative complications

Gasless vs conventional laparoscopy

In the gasless laparoscopy group, procedure-specific complications were reported as small bile leak [26], bile duct stricture [27], bleeding & bruising [25, 27–30] and perforation—small bowel and uterus [27, 30]. Similar complications were reported in those who had conventional laparoscopy. For intraoperative (procedure-specific) complications in the general surgery (19 studies, 806 patients) and gynaecology (6 studies, 636 patients). RCTs subgroup analysis, there was no statistically significant overall difference between the gasless and conventional surgery groups RR 1.04 [CI 0.45, 2.40] and RR 0.66 [CI 0.14, 3.13] respectively (Fig. 2 Supplement). No difference was found in the gynaecology non-RCT subgroup (4 studies, 336 patients).

Gasless laparoscopy vs open surgery

One study comparing gasless versus open surgery versus conventional laparoscopy (CO_2 insufflation) for cholecystectomy had hepatic bleeding in all arms except in the open technique. The intraoperative risk of complication for this study (10 patients) when comparing gasless vs open was high, but statistically not significant RR 3.0 [CI 0.15, 59.89] [28]. The intraoperative risk for gasless versus open gynaecological procedures (2 studies, 180 patients) was not estimable due to zero events in both groups.

Secondary outcomes

Conversion rates

No difference was observed in the conversion rate for general surgical procedures in RCTs (12 studies, 713 patients) for gasless when compared to conventional laparoscopy RR 1.49 [CI 0.71, 3.14], I^2 11% (Fig. 3 Supplement). In the RCT subgroup analysis, the conversion rate was significantly higher for gynaecological procedures (3 studies, 534 patients) for gasless when compared to conventional laparoscopy RR 11.72 [CI 2.26, 60.87], I^2 0%). There was no difference in the conversion rate in non-RCT studies: general surgery (4 studies, 328 patients) RR 0.86 [CI 0.41, 1.83], I^2 0% and gynaecology (7 studies, 569 patients) RR 0.90 [CI 0.15, 5.21], I^2 0%. The funnel plot (Fig. 4 Supplement) did not indicate publication bias with an even distribution of the included studies to estimate the effect of conversion rate.

Overall complications

Gasless vs conventional laparoscopy

There was no difference in the overall complication rate in the gasless group when compared to conventional laparoscopy in the general RCT subgroup (19 studies, 829 patients) RR 0.89 [CI 0.56, 1.43] I^2 17% (Fig. 5 Supplement). No difference was found in the gynaecology RCT subgroup (6 studies, 638 patients) RR 1.08 [CI 0.39, 2.99], I^2 0%. The results of the non-RCT subgroup analyses did not show any difference in the overall complication rates, general surgery (4 studies, 316 patients) RR 0.62 [CI 0.24, 1.64] and gynaecology (2 studies, 230 patients) RR 0.23 [CI 0.01, 4.28].

Gasless laparoscopy vs open surgery

No difference was noted in the subgroup analysis of the overall complications when comparing gasless versus open surgery in the general surgery RCT group (1 study, 10 patients) RR 1.0 [CI 0.08, 11.93]. (Fig. 6 Supplement). Results of the gynaecology RCT subgroup were not estimable due to zero events in either group (2 studies, 180 patients). Similarly, no statistical difference was seen in the overall complication rates in gasless versus open technique in the general surgical non-RCT (4 studies, 186 patients) RR 0.84 [CI 0.34, 2.06], I^2 0% and gynaecology non-RCT (3 studies, 227 patients) RR 0.82; [CI 0.41, 1.66], I^2 0%. There was no evidence of heterogeneity for the results of the non-RCTs.

Operative times

Gasless vs conventional laparoscopy

Operative times were higher for gasless general surgery RCTs (25 studies, 1046 patients) when compared to conventional laparoscopy MD 8.53 [CI 4.68, 12.38], I^2 64% (Fig. 7 Supplement). No difference was seen in the operative times for gynaecology RCTs (6 studies, 296 patients) MD − 0.02 [CI − 8.90, 8.86], I^2 0%. There were no statistically significant differences in the operative times in the general surgery (5 studies, 355 patients) MD 0.52 [CI − 4.87, 5.92], I^2 47% and gynaecology non-RCT (6 studies, 566 patients) MD 8.16 [CI − 1.87, 18.19], I^2 86% non-RCT subgroup analyses.

Gasless laparoscopy vs open surgery

One study (10 patients) included in the general surgery RCT group showed longer operative time for gasless when compared to open surgery MD 10 [CI 0.64, 19.36] (Fig. 8 Supplement). In the gynaecology RCTs (2 studies, 180 patients), operative times were significantly shorter in the gasless group when compared to open technique MD − 18.74 [CI − 29.23, − 8.26], I^2 55%. The operative times in the gynaecology non-RCT (3 studies, 227 patients) were longer for gasless when compared to open surgery, but results were not statistically significant MD 25.11 [CI − 3.34, 53.55] I^2 94%. No difference was found in those who had general surgical procedures (8 studies, 330) in the open versus gasless non-RCT subgroup MD 3.83 [CI − 22.52, 30.18], I^2 95%.

Length of stay

Gasless vs conventional laparoscopy

In the subgroup analysis, no difference was found in the length of hospital stay for general surgical RCTs (10 studies, 452 patients) for gasless when compared to conventional laparoscopy MD 0.24 [CI − 0.14, 0.62], I^2 57% (Fig. 9 Supplement). A statistically significant shorter length of stay was noted in those who had gasless surgery in the gynaecology RCT (3 studies, 493 patients) MD − 0.93 [CI − 1.27, − 0.58], I^2 24% but not in the gynaecology non-RCT group (4 studies, 263 patients) MD − 1.10 [CI − 0.22, 0.02], I^2 0% when compared to conventional laparoscopic surgery. No difference was seen in the general surgery non-RCT group (3 studies, 204 patients) MD 0.04 [CI − 0.80, 0.88], I^2 0%.

Gasless laparoscopy vs open surgery

In the gasless versus open subgroup analysis, shorter length of stay was observed in those who had gasless compared to open technique in the general surgery non-RCT (8 studies, 330 patients) MD − 3.94 [CI − 5.93, − 1.95], I^2 95% and gynaecology non-RCT (3 studies, 227 patients) MD − 1.75 [CI − 2.64, − 0.86], I^2 91%. There was no difference in the general surgery RCT subgroup (2 studies, 110 patients) MD − 2.46 [CI − 5.23, 0.30], I^2 72% (Fig. 10 Supplement).

LMIC subgroup analyses

Due to the paucity of data from LMICs, only two general surgery RCTs from India [13, 31] and two non-RCTs from Ukraine [65, 66] comparing gasless versus conventional laparoscopy were included in a subgroup analysis (Figs. 11–13 supplement). For RCTs (140 patients), there was no difference in the operative times MD 4.82 [CI − 7.12, 16.77], conversion rates RR 1.67 [CI 0.42, 6.60] or overall complication rates RR 1.39 [CI 0.69, 2.79]. For non-RCTs (151 patients), there was no statistically significant differences in operative times MD 0.97; [CI − 2.08, 4.03], conversion rates RR 0.74 [CI 0.30, 1.84] and overall complications rates RR 0.39 [CI 0.15, 1.05].

Discussion

This is the largest systematic review and meta-analysis on gasless laparoscopic surgery for general and gynaecological conditions to date. Most systematic reviews and meta-analysis in the past focussed on safety of cholecystectomy or myomectomies. This review primarily evaluates procedures that could be amenable for gasless laparoscopic intervention over open surgery for a low resource setting.

Due to the weaker level of evidence of several underpowered RCTs and considerable heterogeneity of non-RCTs, it was not possible to draw firm conclusions about the non-inferiority of gasless over conventional laparoscopy or open surgery. Several studies included in the review had incomplete reporting of the methodology, which increased the risk of bias in how RCTs and non-RCTs were assessed. Including zero events in both arms in all the analyses was considered as a robust way of communicating and reporting the results in the meta-analysis [84].

Nearly half of the included RCTs reported mortality and only one third of those reported on short-term follow-up time. Although the majority of studies included in the review were from HICs, the reporting of mortality and follow-up data were better in LMIC studies. High quality randomised intervention studies in low resource settings with a longer follow-up period may not be a feasible starting point to evaluate an intervention. Limited research infrastructure and under funded health systems already bring a lot of pressure on health institutions based in the LMICs. For low resource settings, implementation research methodology such as process evaluation and cohort studies are robust strategies in evaluating complex interventions like laparoscopic surgery in evaluating longer term implications on morbidity and mortality [85, 86].

Conversion rates were considerably higher for gasless compared to conventional laparoscopy in the gynaecology RCT group, but no statistical differences were found in general surgery or the non-RCT subgroup analyses. A further breakdown of this analysis shows that, in 1990s, with the peak interest in gasless technique, studies reported higher conversion rates for adnexal procedures with smaller sample sizes [32, 33]. A myomectomy study by Wang and colleagues in 2011, with a larger sample size, did not report any conversions in either group [34]. One explanation given by Cravello and colleagues was the location of adnexal organs in obese patients resulting in limited views of the pelvis when using the gasless technique [32]. Extreme Trendelenburg position did not improve the view and led to conversion to conventional laparoscopy.

Overall, the reasons reported for conversion from gasless to either CO_2 pneumoperitoneum or open were (1) limited exposure, (2) adhesions, (3) intestinal loops, (4) lower pelvic organs, (5) higher BMIs and (6) limited visualisation of lateral aspects of the abdomen (dependent on the type of abdominal lift device used). Type of pelvic surgery, operator experience, patient body habitus and learning curve may also contribute to the higher conversion rates.

The included studies generally attributed less attention on reporting the training of surgeon and its impact on the outcomes. Several barriers to laparoscopic training already exist in low resource setting, and focussed training in gasless laparoscopy could simplify adoption of laparoscopy over open surgery [5, 10, 87, 88]. In the absence of CO_2 pneumoperitoneum, several reviews and recently conducted RCT by Mishra and colleagues highlighted fewer peri-operative complications and better physiological tolerance with gasless technique [13, 17, 18, 89]. Wang and colleagues discuss that during gasless laparoscopy, instruments traditionally used for open gynaecological procedures simplify intraoperative suturing of the uterus, increase precision during ligation and reduce complications [34].

Longer operative times could be attributed to the procedures' complexities within each subgroup or limited views whilst operating. Hence, device modification is essential to provide uniform lift of the abdominal wall, allowing better visualisation of the peritoneal cavity and achieving comparable views to conventional laparoscopy. The operative times were considerably shorter for gynaecology RCTs but longer for non-RCTs when comparing gasless versus open. The gynaecology RCTs included the procedure of myomectomy, whereas the non-RCTs had hysterectomies and adnexal surgeries. Longer operative times could be attributed to the complexity of the procedures or limited views due as discussed earlier.

The length of hospital stay (LoS) was shorter in patients who underwent less complicated gynaecological procedures using the gasless technique when compared to conventional laparoscopy. The LoS was also considerably shorter for those who underwent gasless when compared to the open surgical technique. A systematic review for gasless myomectomy conducted by Liu and colleagues also found shorter length of stay [18].

Several studies included in the analysis comparing gasless versus open surgery had complex abdominal procedures that may not be suitable for surgeons with limited experience. Major gastrointestinal and gynaecological resectional surgery is not suitable for the gasless approach or for undertaking in level 1 district hospitals, which lack the necessary perioperative support. Such major surgery demands a high level of expertise and sub-specialisation which is concentrated in level 3 facilities. Rather, gasless laparoscopy is best suited to diagnostic procedures or simple, single-quadrant resection, such as appendicectomy, cholecystectomy, salpingectomy, tubal ligation, oophorectomy and myomectomy and in non-obese patients with lower anaesthetic risk.

The introduction of laparoscopic surgery in resource limited settings faces several challenges due to the lack of infrastructure, training opportunities, surgical hierarchy, limited workforce and financial constraints [9, 90]. Nearly 90% of gastrointestinal procedures in low-income settings are operated using open surgery and have higher complication rates compared to laparoscopy [6–8]. The findings of this study should encourage policymakers in low resource settings to prioritise minimal access surgery over open surgery in selective general and gynaecological procedures. Gasless laparoscopy has the potential to be a cost-effective technology to accelerate the adoption of minimally invasive surgery in low resource settings.

There were several limitations to this review. Most studies did not grade the complications resulting from the surgical procedure, which restricts the measurement of the quality of improving health care delivery [91]. The severity of intra- and postoperative complications may vary: a comparison of overall complications may miss unequally distributed severe complications between interventions. Therefore, these findings should be interpreted with great caution due to this limitation.

No subgroup analysis was conducted based on the surgical expertise, type of anaesthesia, ASA score or the use of different abdominal wall lift devices as majority cases were done under general anaesthesia in low-risk patients. Previous operative experience, hours of training, type of lift device and pain scores were either under-reported or disparate across studies to allow meaningful sub-group analyses. Some analyses increased heterogeneity due to the inclusion of different types of procedures within a study. Most studies conducted in HICs and tertiary hospitals of LMICs are less relevant in a low resource setting and are less likely to give a plausible explanation for the outcomes expected. Hence, this review's findings cannot be generalised and should act as a guide to conduct high quality studies relevant to the context and address the burden of surgical diseases due to abdominal conditions.

Author Contributions

NA, DGJ, BS, TE and RK came up with the research question and designed the protocol. NA did the literature search, study selection, quality assessment and data extraction. WB independently reviewed title, abstract, full text review and quality of selected studies. The selected studies were reviewed by AM and LB. JG expert in gasless provided critical comments. NK assisted with the search strategies. NA did the statistical analysis with advice from BS. NA wrote the manuscript, designed the tables, figures and appendices.

DGJ, BS, TE and RK contributed to critical revisions. All authors approved final manuscript.

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Declarations

Disclosures NA, AM, LB and JG are part of an inter-disciplinary collaborative research group investigating the performance of a new gasless lift device. N. Aruparayil, W. Bolton, A. Mishra, L. Bains, J. Gnanaraj, R. King, T. Ensor, N. King, D. Jayne, B. Shinkins have no conflicts of interest or financial ties to disclose.

Ethical approval As it was a systematic review and meta-analysis—no IRB approval or written consent forms were required.

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