Robot-assisted laparoscopic surgery versus conventional laparoscopic surgery in randomized controlled trials: A systematic review and meta-analysis

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Abstract

Importance

This review provides a comprehensive comparison of treatment outcomes between robot-assisted laparoscopic surgery (RLS) and conventional laparoscopic surgery (CLS) based on randomly-controlled trials (RCTs).

Objectives

We employed RCTs to provide a systematic review that will enable the relevant community to weigh the effectiveness and efficacy of surgical robotics in controversial fields on surgical procedures both overall and on each individual surgical procedure.

Evidence review

A search was conducted for RCTs in PubMed, EMBASE, and Cochrane databases from 1981 to 2016. Among a total of 1,517 articles, 27 clinical reports with a mean sample size of 65 patients per report (32.7 patients who underwent RLS and 32.5 who underwent CLS), met the inclusion criteria.

Findings

CLS shows significant advantages in total operative time, net operative time, total complication rate, and operative cost ($p < 0.05$ in all cases), whereas the estimated blood loss was less in RLS ($p < 0.05$). As subgroup analyses, conversion rate on colectomy and length of hospital stay on hysterectomy statistically favors RLS ($p < 0.05$).

Conclusions

Despite higher operative cost, RLS does not result in statistically better treatment outcomes, with the exception of lower estimated blood loss. Operative time and total complication rate are significantly more favorable with CLS.

Introduction

Although conventional laparoscopic surgery (CLS) allows more rapid postoperative recovery and has superior cosmetic outcomes compared with open laparotomy, CLS has several technical drawbacks [1] including a limited range of motion of instruments and related loss of dexterity, fixed instrument tips, and an inadequate visual field associated with an unstable camera view and assistant traction [2]. The introduction of robot-assisted laparoscopic surgery (RLS) was expected to open new avenues through its potential to overcome the drawbacks of CLS as a result of better ergonomics and enhanced dexterity with tremor filtration, numerous instrumental tips for the EndoWrist instrument, and 3D optical systems [3, 4]. Due to these advances, there is encouraging emerging evidence supporting RLS as an alternative technique to CLS.

In spite of the aforementioned advantages of RLS there are several controversial aspects of this approach, such as operative time, blood loss, conversion rate, complication rate, length of hospital stay, and operative cost. Numerous studies have reported clinical outcomes with regard to these aspects, and meta-analyses have assessed the pros and cons of robotics in various departments, including surgery, urology, and gynecology [5–14]. However, robotics is a relatively new surgical approach and RCT data have only recently become commonly available. Thus, there is a limited number of RCTs on each surgical procedure [3], and the lack of robust clinical evidence has frequently been emphasized [4, 15]. On incorporating all surgical procedures; previous statistically nonsignificant results due to limited RCT evidence for individual surgical procedure, may become statistically significant because of greater statistical power.

The scope of meta-analyses exclusively on RCTs [1, 16, 17] considers only a specific surgical procedure to convey more homogenous statistical results, compared to the that of a meta-analysis across surgical procedures [18]. However, the intrinsic properties of robotic instruments throughout overall surgical procedures could be mistakenly reported as the results of the unique properties of the particular surgical procedure. In contrast, the scope of meta-analysis [18] has been enlarged to combine RCTs across surgical procedures. Nonetheless, this regrettably omitted, among others, cholecystectomy and did not present forest plots with subgroup analyses. The forest plots with subgroup analysis of each surgical procedure intuitively would embrace the need for further floods of separate meta-analysis for each surgical procedure and encourage the combined discussion on the surgical robotics across surgical procedures. Our effort for integrating the previous individual studies and meta-analyses aims to provide the basis to statistically weigh the effectiveness and efficacy of surgical robotic instruments in controversial fields on surgical procedures both overall and on each individual surgical procedure.

Materials and methods

Identification of studies

A systematic review of the literature was conducted by electronic search to find RCT studies with date of publication from 1981 to 2016 inclusively on PubMed, EMBASE, and Cochrane databases with the following search strategy: mention at least one of robot, robotic, robotics, robotically, robot-assisted, robotic-assisted and, at the same time, at least one of laparoscopic, laparoscopy, laparoscope, since both RLS and CLS should be discussed; RCT evidence with a keyword of at least one of randomized, randomised, random, and RCT. It should be noted that Web of Science (Core) and SCOPUS were additionally used to find the full text for the articles that were identified by the Excerpta Medical Database of EMBASE. Two independent researchers (HFR and SHN) extracted the following data from selected studies: references,

study type, population characteristics, and relevant clinical outcomes. Discrepancies between the two authors were reviewed and resolved by the senior investigator (JMK). Protocol.io: http://dx.doi.org/10.17504/protocols.io.k7ucznw

Eligibility criteria

The criteria for eligibility of evidence were as follows: the original article should present a RCT comparison between RLS and CLS in human subjects with basic demographic information, including at least one of the following aspects: total operative time (Total-OT), net operative time (Net-OT), estimated blood loss (EBL), number of transfusions (Transf), conversion rate (Conv), total complication rate (Total-Cx), intra-operative complication rate (Intra-Cx), post-operative complication rate (Post-Cx), length of hospital stay (LOHS), and total operative costs (Cost). Additionally, this study excluded RCT studies performed for simulation and training purposes.

Statistical methods & bias

Cochrane Review Manager (version 5.3) enabled most of the statistical analysis, including bias assessments of RCTs, whereas the supplemental R script (S2 File) conveyed all the information to reproduce the results of Begg's test and Egger's test. A p-value < 0.05 was considered statistically significant. PRISMA checklist was employed as a protocol of meta-analysis and its guideline was followed [19]. Fixed-effects model was employed if the Higgin's I^2 statistics were < 50%; otherwise, a random-effects model was applied. In addition to bias assessments on individual RCT evidence, publication biases were visually assessed based on funnel plots. Then, publication bias was numerically evaluated by Begg's test [20] and Egger's test [21], respectively, based on rank correlation and weighted linear regression.

Handling operative outcomes

When extracting the numerical information from original articles, some do not report, for example, the standard deviations. If the relevant numerical values are missing from the original articles but reported in the meta-analysis, we copied the values from the corresponding meta-analysis. Otherwise, a request was sent to the corresponding author for the missing data. If the requested information was not available or was not received within 30 days after the request date, we imputed the missing standard deviations by taking the median value of the included studies [22].

Total-OT and Net-OT. If an article did not explicitly describe the method used to measure operative time, we regarded it as Total-OT. However, if an article distinguishes Total-OT from pure procedural time by, for example, skin-to-skin operative time, we treated it as Net-OT in this study.

Intra-Cx, Post-Cx, and Total-Cx. If an original article explicitly described whether the reported number of complications referred to either intra-operative or post-operative complication rates, we specifically reflected this. However, if the author did not make this distinction, we entered the number into the total complication rate (Total-Cx). In addition, Total-Cx was assumed to be the sum of intra-operative complication rate (Intra-Cx) and post-operative complication rate (Post-Cx), unless the original article [23] reported values for Intra-Cx and Post-Cx that did not add up to the reported Total-Cx.

Cost. The operative costs were divided by 1,000, since the forest plot of Cochrane Review Manager software does not seem to visually handle values greater than 1,000. However, the Z-values before and after the division by 1,000 were found to be the same numerically. If the operative costs were reported in currency other than US dollars, we indicated their currency.
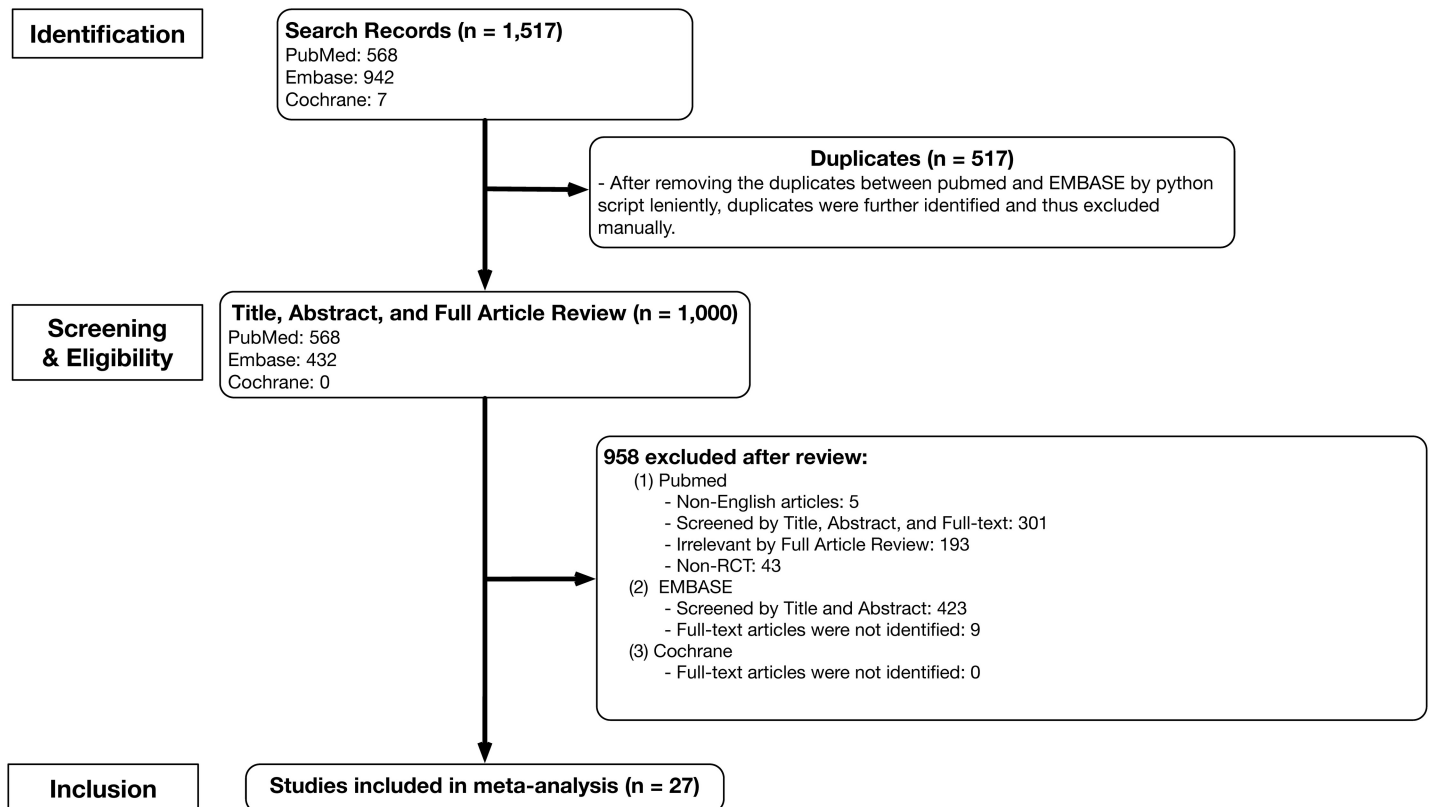
Fig 1. Schematic representation of the study selection process. This study attempted to screen leniently and perform a full-text search whenever possible in order to more confidently determine whether to include or exclude studies and extract information necessary for meta-analysis [50].

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Results

Literature search

As illustrated in Fig 1, our search strategy identified 1,517 studies (568 from PubMed, 942 from EMBASE, and 7 from Cochrane) comparing treatment outcomes between RLS and CLS. After removing duplicate articles in the EMBASE database and Cochrane database that were also found in the PubMed database, a total of 1,000 articles (568 PubMed studies, 432 EMBASE studies, and 0 Cochrane studies) were examined. After reviewing the titles, abstracts, and full texts, 27 published studies [23–49] met all inclusion criteria and were included in the meta-analysis.

Study characteristics

S1 Table lists the characteristics of all studies that compared the RCT treatment outcomes between RLS and CLS. Among the 27 RCT studies, with a mean sample size of 65 patients per study (32.7 patients for RLS and 32.5 patients for CLS), seven studies in gynecology, 15 in surgery, and five in urology were selected for inclusion in the analysis. With respect to gastrointestinal reconstruction studies, after gastrectomy, Sanchez *et al.* [48] restored continuation of the gastrointestinal tract via Roux-en-Y gastrojejunostomy. The type of robot employed in the included studies was the da Vinci system, with the exception of "MONA" by Cadiere *et al.* [29], "AESOP" by Aiono *et al.* [24] and Morino *et al.* [37], and "ZEUS-AESOP" by Nio *et al.* [41].

The previously described imputation methodology [22] was applied for the missing standard deviation of Total-OT [29, 34, 35, 37, 48], Net-OT [35], EBL [33–35, 38], LOHS [33–35, 37, 38, 41, 46, 48], and Cost [37, 38]. We had difficulty determining the number of patients allocated to RLS and CLS from one hysterectomy study [23], therefore the number of patients was taken from its meta-analysis [7]. Nakadi *et al*. reported two distinct Cost categories for robotic surgery as "Total" and "Total (with instrumentation costs in relation to the real OR occupation time: 4%)" [40]. For this study we chose to enter the latter as Cost, since the authors seemed to suggest that this was a more reasonable representation of the total robotic surgery cost. Three studies [38–40] reported Cost in Euros.

Quality assessments

Bias assessments of RCTs in previous reviews [1, 16–18, 51–56] differed according to the judgements of the authors reviewing the same studies. Bias assessments of RCTs in previous reviews have been typically performed in terms of random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases. For example, the results of bias assessments of one colectomy study [27] for the aforementioned seven bias aspects were "+—? —? +?" in one meta-analysis [53] and "+ +—- + + -" in the other meta-analysis [1], where +, -, and? denote lower risk, high risk, and, unclear risk, respectively, for the risk judgement. This kind of discrepancy could be found frequently among meta-analyses. Thus, our quality assessments (Fig 2) were performed rather conservatively with a blank space for denoting unclear risk in consideration of previous assessments [1, 16–18, 51–56]. The risk of bias in the RCT was high and unclear overall.

Treatment outcomes

Fig 3 shows the results of comparison of the treatment outcomes between RLS and CLS. Since the Higgin's I^2 was < 50%, the fixed-effect model was applied for EBL, Transf, Conv, Total-Cx, and Intra-Cx, whereas the random-effect model was employed for Total-OT, Net-OT, Post-Cx, LOHS, and Cost. Total-OT, Net-OT, Total-Cx, and Cost were statistically shown to favor CLS with pooled mean differences [95% confidence interval] of 16.81 [6.20, 27.42] with the high heterogeneity ($P < 0.05$, $I^2 = 94\%$) (Fig 3A), 11.48 [0.62, 22.34] with the high heterogeneity ($P < 0.05$, $I^2 = 92\%$) (Fig 3B), 1.46 [1.05, 2.03] with no evidence of observed heterogeneity ($P = 0.17$, $I^2 = 26\%$) (Fig 3H), and 1.73 [0.95, 2.50] with the high heterogeneity ($P < 0.05$, $I^2 = 95\%$) (Fig 3C), respectively, whereas EBL was shown to favor RLS with pooled mean difference of -6.47 and 95% CI of [-9.61, -3.34] with no evidence of observed heterogeneity ($P = 0.41$, $I^2 = 3\%$) (Fig 3D). No statistically significant difference between the groups was found for Transf, Intra-Cx, Post-Cx, or LOHS. With respect to forest plots on subgroups, Conv on colectomy and LOHS on hysterectomy statically favors RLS with pooled mean differences [95% confidence interval] of 0.25 [0.07, 0.91] with no evidence of observed heterogeneity ($P = 0.27$, $I^2 = 24\%$) (Fig 3G) and -0.56 [-1.04, -0.09] with the high heterogeneity ($P < 0.05$, $I^2 = 73\%$) (Fig 3F), respectively.

Publication bias

Publication bias was assessed by funnel plots between the two groups. The funnel plots showed symmetric distributions indicating no evidence of publication bias among the studies (S1 Fig). In addition, with respect to Total-OT, there did not appear to be any strong evidence of publication bias from either Begg's test (*p* = 0.2072) or Egger's test (*p* = 0.2079) (S2 File).

Fig 2. Risk of bias assessments. Bias assessments of RCTs were performed in terms of random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases. +, -, and a blank space denote lower risk, high risk, and unclear risk, respectively, for the risk judgement.

Discussion

This review provides a comprehensive comparison between RLS and CLS based on RCT studies in order to investigate the general trend of treatment outcomes for the controversial aspects of these approaches. Besides, the forest plots with subgroup analysis provide necessary information not only to investigate the comparison of treatment outcomes from the unique properties of the particular surgical procedure, but also to facilitate a more combined discussion from experts across various surgical procedures. From the statistical findings, it is concluded that despite its higher cost, RLS does not result in statistically improved treatment outcomes, with the exception of a lower EBL. Rather, Total-OT, Net-OT, and Total-Cx significantly favor CLS.
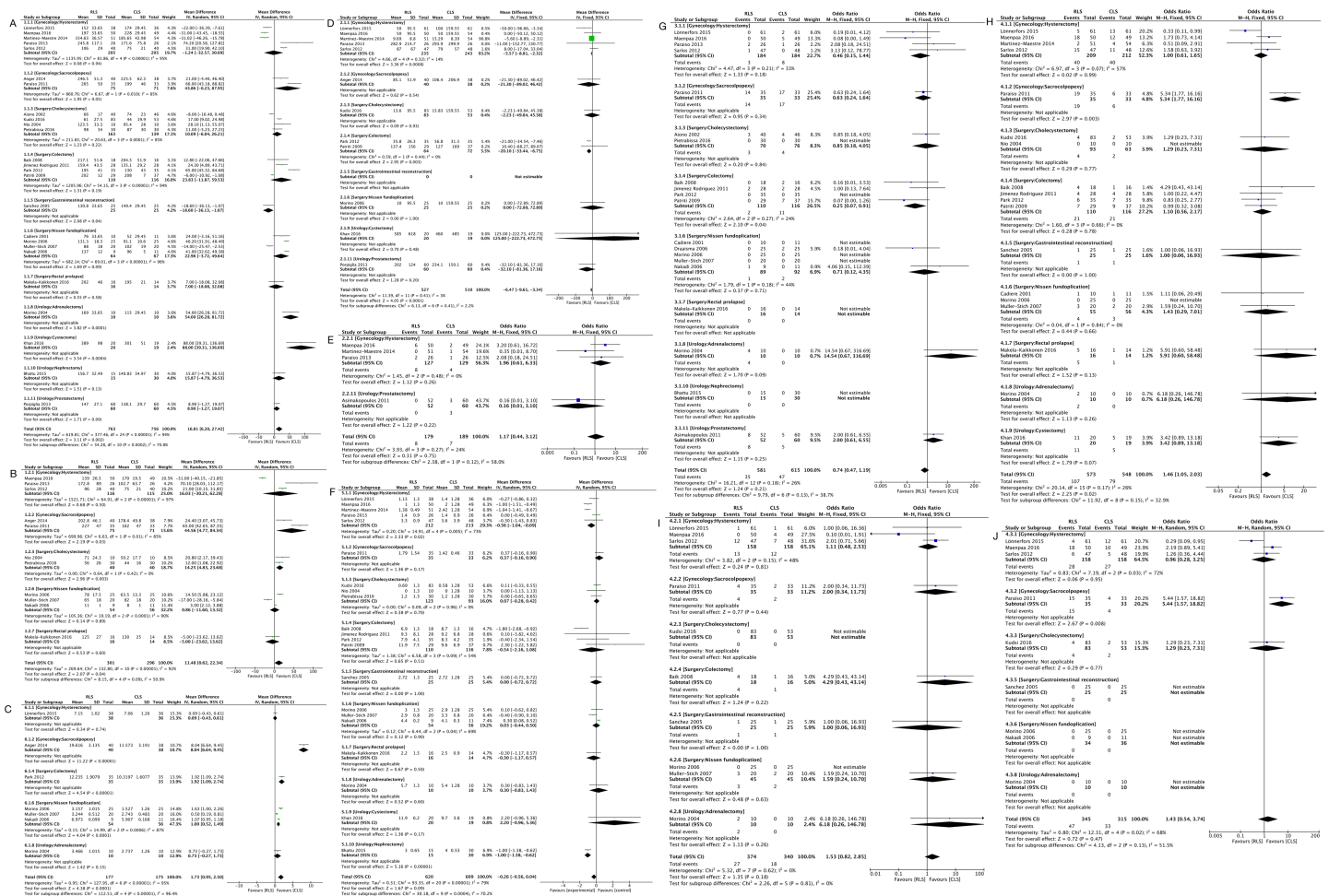
Fig 3. Forest plots with subgroups. Comparison of RLS and CLS with respect to (A) total operative time, (B) net operative time, (C) total operative cost, (D) estimated blood loss, (E) blood transfusion, (F) length of hospital stay, (G) conversion, (H) total complication, (I) intra-operative complication, and (J) post-operative complication. Note that, although Cochrane RevMan reports "Not estimable" for the study whose value include "0" value and does not take the study into account for the forest-plot analysis, the present study reports all available values from the studies for completeness. OR: odds ratio; WMD: weighted mean difference.

Because of the greater statistical power attained by integrating relevant RCT evidences, this study is able to report that, for example, Total-OT and Net-OT are significantly lower for CLS, although Liao *et al.* [10] and Albright *et al.* [16] reported that the operative time was insignificantly lower in CLS based on RCT evidence. Xiong *et al.* and Chuan *et al.* attributed the lower EBL of RLS to the use of robotic devices that provided better stability and avoided the damage caused by shaking hands in CLS and provided a greater field of view for detection of both large and small vessels [6, 57].

Clinical heterogeneity introduced by integrating various surgical procedures may contribute to the deviation from previous meta-analyses findings, presumably reflecting the intrinsic properties of each surgical procedure such as retroperitoneal involvement of prostatectomy [58]. The subgroup analyses favoring RLS on Conv on colectomy and LOHS on hysterectomy could be reasoned in association with properties of surgical robotics as follows: Lin *et al.* proposed that a lower Conv may be attributed to superior exposure and visualization of the operating field [3]. Ran *et al.* report that RLS was superior to CLS in terms of EBL and Conv, and proposed that the increased precision and dexterity of robotic platforms may contribute to these findings [7]. Chuan *et al.* reported that RLS was superior to CLS in terms of LOHS, and proposed that the more subtle operative technique and reduced level of invasiveness may be responsible for their findings [6]. Regarding Conv, surgeons might try a new surgical technology on a relatively less complicated surgery, which possibly distorts the outcome and results in inconsistent statistical significance. Thus, in consideration of the level of difficulties encountered in different surgeries, it may remain to be seen whether Conv would support RLS when more data are accumulated.

The present study stems from the motivation to contribute to the advancement in meta-analysis on surgical robotics by listing the limitations, followed by preliminary suggestions, if possible. Firstly, as pointed out by O'Neill *et al.* [4], some studies did not indicate explicitly whether the docking time for RLS was included in the operative time. The main cause of this confusion lies in the absence of standard ways of comparing operative time between the two groups. Some articles do not explicitly describe specifically how the RLS operative time— which can be broken into several pieces such as skin-to-skin, robot set-up time, etc.—was measured. Furthermore, although some original articles set strict rules for measuring operative time, unfortunately the terminology differs across studies, for example, "Operation time" [35], "Net operating time" [23], "Procedure" [25], "Dissection time" [41, 46], "skin-to-skin time" [38], "Effective operative time" [39], etc. These differences in terminology create additional difficulties in identifying the actual operative time. In this regard, for this study we chose to use "Net operative time," which is intuitively different from "Total operative time".

Secondly, the difference of indications across studies could have resulted in the inclusion of patients from each study variable. For example, in addition to the apparent discrepancy between the patient's conditions and clinical indications, not all the critical criteria of one study [58] could be possibly matched and compared against those of another study [47], due to insufficient information. In this regard, one study acknowledged that "[t]he different inclusion criteria and surgical techniques could potentially justify the differences between these results" [47]. Thus, please be aware of the limitation imposed by heterogeneities, which diminished the significance of the statistical results of weighing advantages and disadvantages.

Thirdly, none of the studies evaluated the degree of surgeon proficiency between RLS and CLS in the face of a new technology like robotics with an established technology like laparoscopy. According to Finkelstein *et al.*, "to become proficient at [laparoscopic radical prostatectomy] or [robotic-assisted laparoscopic radical prostatectomy], [. . .] a surgeon must perform anywhere from 8 to 12 cases to as many as 200 cases" [59]. In this regard, it may be worth taking into account surgeon experience, for example, number of surgeries, before comparing other aspects of a surgery.

Finally, whenever standard deviations were not available, imputations of the standard deviations were conducted. Although it is reported that "imputing missing standard deviations in meta-analyses can provide accurate results" [22], awareness of this limitation should be noted. It is proposed that future studies should be encouraged to report standard deviations whenever possible.

Supporting information

S1 Fig. Funnel plots. (A) total operative time, (B) net operative time, (C) total operative cost, (D) estimated blood loss, (E) blood transfusion, (F) length of hospital stay, (G) conversion, (H) total complication, (I) intra-operative complication, and (J) post-operative complication.
(ZIP)

S1 Table. Patient demographic and clinical characteristics. Total-OT: total operative time, Net-OT: net operative time, Cost: total operative cost, EBL: estimated blood loss, Transf: number of transfusions, LOHS: length of hospital stay, Conv: conversion rate, Total-Cx: total complication rate, Intra-Cx: intra-operative complication rate, Post-Cx: post-operative complication rate.
(DOCX)

S1 File. PRISMA checklist.
(DOC)

S2 File. R script for Begg's test and Egger's test. Tests were performed for total operative time.
(R)

Author Contributions

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Formal analysis: Hyunsuk Frank Roh, Seung Hyuk Nam.

Funding acquisition: Jung Mogg Kim.

Investigation: Hyunsuk Frank Roh.

Methodology: Hyunsuk Frank Roh, Seung Hyuk Nam.

Project administration: Jung Mogg Kim.

Resources: Hyunsuk Frank Roh.

Software: Hyunsuk Frank Roh.

Validation: Jung Mogg Kim.

Visualization: Hyunsuk Frank Roh.

Writing – original draft: Hyunsuk Frank Roh, Jung Mogg Kim.

Writing – review & editing: Hyunsuk Frank Roh, Seung Hyuk Nam, Jung Mogg Kim.

References

1. Liao G, Zhao Z, Lin S, Li R, Yuan Y, Du S, et al. Robotic-assisted versus laparoscopic colorectal surgery: a meta-analysis of four randomized controlled trials. World J Surg Oncol. 2014; 12: 122. https://doi.org/10.1186/1477-7819-12-122 PMID: 24767102

2. Tekkis PP, Senagore AJ, Delaney CP, Fazio VW. Evaluation of the learning curve in laparoscopic colorectal surgery: comparison of right-sided and left-sided resections. Ann Surg. 2005; 242: 83–91. https://doi.org/10.1097/01.sla.0000167857.14690.68 PMID: 15973105

3. Lin S, Jiang HG, Chen ZH, Zhou SY, Liu XS, Yu JR. Meta-analysis of robotic and laparoscopic surgery for treatment of rectal cancer. World J Gastroenterol. 2011; 17: 5214–20. https://doi.org/10.3748/wjg.v17.i47.5214 PMID: 22215947

4. O'Neill M, Moran PS, Teljeur C, O'Sullivan OE, O'Reilly BA, Hewitt M, et al. Robot-assisted hysterectomy compared to open and laparoscopic approaches: systematic review and meta-analysis. Arch Gynecol Obstet. 2013; 287: 907–18. https://doi.org/10.1007/s00404-012-2681-z PMID: 23291924

5. Brandao LF, Autorino R, Laydner H, Haber GP, Ouzaid I, De Sio M, et al. Robotic versus laparoscopic adrenalectomy: a systematic review and meta-analysis. Eur Urol. 2014; 65: 1154–61. https://doi.org/10.1016/j.eururo.2013.09.021 PMID: 24079955

6. Chuan L, Yan S, Pei-Wu Y. Meta-analysis of the short-term outcomes of robotic-assisted compared to laparoscopic gastrectomy. Minim Invasive Ther Allied Technol. 2014: 1–8. https://doi.org/10.3109/13645706.2013.871294

7. Ran L, Jin J, Xu Y, Bu Y, Song F. Comparison of robotic surgery with laparoscopy and laparotomy for treatment of endometrial cancer: a meta-analysis. PLoS One. 2014; 9: e108361. https://doi.org/10.1371/journal.pone.0108361 PMID: 25259856

8. Cao C, Manganas C, Ang SC, Yan TD. A systematic review and meta-analysis on pulmonary resections by robotic video-assisted thoracic surgery. Ann Cardiothorac Surg. 2012; 1: 3–10. https://doi.org/10.3978/j.issn.2225-319X.2012.04.03 PMID: 23977457

9. Cundy TP, Harling L, Marcus HJ, Athanasiou T, Darzi AW. Meta analysis of robot-assisted versus conventional laparoscopic fundoplication in children. J Pediatr Surg. 2014; 49: 646–52. https://doi.org/10.1016/j.jpedsurg.2013.12.014 PMID: 24726129

10. Liao GX, Xie GZ, Li R, Zhao ZH, Sun QQ, Du SS, et al. Meta-analysis of outcomes compared between robotic and laparoscopic gastrectomy for gastric cancer. Asian Pac J Cancer Prev. 2013; 14: 4871–5. PMID: 24083761

11. Markar SR, Karthikesalingam AP, Hagen ME, Talamini M, Horgan S, Wagner OJ. Robotic vs. laparoscopic Nissen fundoplication for gastro-oesophageal reflux disease: systematic review and meta-analysis. Int J Med Robot. 2010; 6: 125–31. https://doi.org/10.1002/rcs.309 PMID: 20506440

12. Moran PS, O'Neill M, Teljeur C, Flattery M, Murphy LA, Smyth G, et al. Robot-assisted radical prostatectomy compared with open and laparoscopic approaches: a systematic review and meta-analysis. Int J Urol. 2013; 20: 312–21. https://doi.org/10.1111/iju.12070 PMID: 23311943

13. Serati M, Bogani G, Sorice P, Braga A, Torella M, Salvatore S, et al. Robot-assisted Sacrocolpopexy for Pelvic Organ Prolapse: A Systematic Review and Meta-analysis of Comparative Studies. Eur Urol. 2014; 66: 303–18. https://doi.org/10.1016/j.eururo.2014.02.053 PMID: 24631406

14. Wang Z, Zheng Q, Jin Z. Meta-analysis of robot-assisted versus conventional laparoscopic Nissen fundoplication for gastro-oesophageal reflux disease. ANZ J Surg. 2012; 82: 112–7. https://doi.org/10.1111/j.1445-2197.2011.05964.x PMID: 22510118

15. Braga LH, Pace K, DeMaria J, Lorenzo AJ. Systematic review and meta-analysis of robotic-assisted versus conventional laparoscopic pyeloplasty for patients with ureteropelvic junction obstruction: effect on operative time, length of hospital stay, postoperative complications, and success rate. Eur Urol. 2009; 56: 848–57. https://doi.org/10.1016/j.eururo.2009.03.063 PMID: 19359084

16. Albright BB, Witte T, Tofte AN, Chou J, Black JD, Desai VB, et al. Robotic Versus Laparoscopic Hysterectomy for Benign Disease: A Systematic Review and Meta-Analysis of Randomized Trials. J Minim Invasive Gynecol. 2016; 23: 18–27. https://doi.org/10.1016/j.jmig.2015.08.003 PMID: 26272688

17. Allan C, Ilic D. Laparoscopic versus Robotic-Assisted Radical Prostatectomy for the Treatment of Localised Prostate Cancer: A Systematic Review. Urol Int. 2016; 96: 373–8. https://doi.org/10.1159/000435861 PMID: 26201500

18. Broholm M, Onsberg Hansen I, Rosenberg J. Limited Evidence for Robot-assisted Surgery: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. Surg Laparosc Endosc Percutan Tech. 2016; 26: 117–23. https://doi.org/10.1097/SLE.0000000000000248 PMID: 26766316

19. Moher D, Liberati A, Tetzlaff J, Altman DG, Group P. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Med. 2009; 6: e1000097. https://doi.org/10.1371/journal.pmed.1000097 PMID: 19621072

20. Begg CB, Mazumdar M. Operating characteristics of a rank correlation test for publication bias. Biometrics. 1994; 50: 1088–101. PMID: 7786990

21. Egger M, Davey Smith G, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ. 1997; 315: 629–34. PMID: 9310563

22. Furukawa TA, Barbui C, Cipriani A, Brambilla P, Watanabe N. Imputing missing standard deviations in meta-analyses can provide accurate results. J Clin Epidemiol. 2006; 59: 7–10. https://doi.org/10.1016/j.jclinepi.2005.06.006 PMID: 16360555

23. Sarlos D, Kots L, Stevanovic N, von Felten S, Schar G. Robotic compared with conventional laparoscopic hysterectomy: a randomized controlled trial. Obstet Gynecol. 2012; 120: 604–11. https://doi.org/10.1097/AOG.0b013e318265b61a PMID: 22914470

24. Aiono S, Gilbert JM, Soin B, Finlay PA, Gordan A. Controlled trial of the introduction of a robotic camera assistant (EndoAssist) for laparoscopic cholecystectomy. Surg Endosc. 2002; 16: 1267–70. https://doi.org/10.1007/s00464-001-9174-7 PMID: 12235507

25. Anger JT, Mueller ER, Tarnay C, Smith B, Stroupe K, Rosenman A, et al. Robotic compared with laparoscopic sacrocolpopexy: a randomized controlled trial. Obstet Gynecol. 2014; 123: 5–12. https://doi.org/10.1097/AOG.0000000000000006 PMID: 24463657

26. Asimakopoulos AD, Pereira Fraga CT, Annino F, Pasqualetti P, Calado AA, Mugnier C. Randomized comparison between laparoscopic and robot-assisted nerve-sparing radical prostatectomy. J Sex Med. 2011; 8: 1503–12. https://doi.org/10.1111/j.1743-6109.2011.02215.x PMID: 21324093

27. Baik SH, Ko YT, Kang CM, Lee WJ, Kim NK, Sohn SK, et al. Robotic tumor-specific mesorectal excision of rectal cancer: short-term outcome of a pilot randomized trial. Surg Endosc. 2008; 22: 1601–8. https://doi.org/10.1007/s00464-008-9752-z PMID: 18270772

28. Bhattu AS, Ganpule A, Sabnis RB, Murali V, Mishra S, Desai M. Robot-Assisted Laparoscopic Donor Nephrectomy vs Standard Laparoscopic Donor Nephrectomy: A Prospective Randomized Comparative Study. J Endourol. 2015; 29: 1334–40. https://doi.org/10.1089/end.2015.0213 PMID: 26414847

29. Cadiere GB, Himpens J, Vertruyen M, Bruyns J, Germay O, Leman G, et al. Evaluation of telesurgical (robotic) NISSEN fundoplication. Surg Endosc. 2001; 15: 918–23. https://doi.org/10.1007/s004640000217 PMID: 11605106

30. Draaisma WA, Ruurda JP, Scheffer RC, Simmermacher RK, Gooszen HG, Rijnhart-de Jong HG, et al. Randomized clinical trial of standard laparoscopic versus robot-assisted laparoscopic Nissen fundoplication for gastro-oesophageal reflux disease. Br J Surg. 2006; 93: 1351–9. https://doi.org/10.1002/bjs.5535 PMID: 17058295

31. Jimenez Rodriguez RM, Diaz Pavon JM, de La Portilla de Juan F, Prendes Sillero E, Hisnard Cadet Dussort JM, Padillo J. [Prospective randomised study: robotic-assisted versus conventional laparoscopic surgery in colorectal cancer resection]. Cir Esp. 2011; 89: 432–8. https://doi.org/10.1016/j.ciresp.2011.01.017 PMID: 21530948

32. Khan MS, Gan C, Ahmed K, Ismail AF, Watkins J, Summers JA, et al. A Single-centre Early Phase Randomised Controlled Three-arm Trial of Open, Robotic, and Laparoscopic Radical Cystectomy (CORAL). Eur Urol. 2016; 69: 613–21. https://doi.org/10.1016/j.eururo.2015.07.038 PMID: 26272237

33. Kudsi OY, Castellanos A, Kaza S, McCarty J, Dickens E, Martin D, et al. Cosmesis, patient satisfaction, and quality of life after da Vinci Single-Site cholecystectomy and multiport laparoscopic cholecystectomy: short-term results from a prospective, multicenter, randomized, controlled trial. Surg Endosc. 2016.

34. Lonnerfors C, Reynisson P, Persson J. A randomized trial comparing vaginal and laparoscopic hysterectomy vs robot-assisted hysterectomy. J Minim Invasive Gynecol. 2015; 22: 78–86. https://doi.org/10.1016/j.jmig.2014.07.010 PMID: 25045857

35. Maenpaa MM, Nieminen K, Tomas EI, Laurila M, Luukkaala TH, Maenpaa JU. Robotic-assisted vs traditional laparoscopic surgery for endometrial cancer: a randomized controlled trial. Am J Obstet Gynecol. 2016; 215: 588 e1–e7.

36. Makela-Kaikkonen J, Rautio T, Paakko E, Biancari F, Ohtonen P, Makela J. Robot-assisted vs laparoscopic ventral rectopexy for external or internal rectal prolapse and enterocele: a randomized controlled trial. Colorectal Dis. 2016; 18: 1010–5. https://doi.org/10.1111/codi.13309 PMID: 26919191

37. Morino M, Beninca G, Giraudo G, Del Genio GM, Rebecchi F, Garrone C. Robot-assisted vs laparoscopic adrenalectomy: a prospective randomized controlled trial. Surg Endosc. 2004; 18: 1742–6. https://doi.org/10.1007/s00464-004-9046-z PMID: 15809781

38. Morino M, Pellegrino L, Giaccone C, Garrone C, Rebecchi F. Randomized clinical trial of robot-assisted versus laparoscopic Nissen fundoplication. Br J Surg. 2006; 93: 553–8. https://doi.org/10.1002/bjs.5325 PMID: 16552744

39. Muller-Stich BP, Reiter MA, Wente MN, Bintintan VV, Koninger J, Buchler MW, et al. Robot-assisted versus conventional laparoscopic fundoplication: short-term outcome of a pilot randomized controlled trial. Surg Endosc. 2007; 21: 1800–5. https://doi.org/10.1007/s00464-007-9268-y PMID: 17353978

40. Nakadi IE, Melot C, Closset J, DeMoor V, Betroune K, Feron P, et al. Evaluation of da Vinci Nissen fundoplication clinical results and cost minimization. World J Surg. 2006; 30: 1050–4. https://doi.org/10.1007/s00268-005-7950-6 PMID: 16736336

41. Nio D, Bemelman WA, Busch OR, Vrouenraets BC, Gouma DJ. Robot-assisted laparoscopic cholecystectomy versus conventional laparoscopic cholecystectomy: a comparative study. Surg Endosc. 2004; 18: 379–82. https://doi.org/10.1007/s00464-003-9133-6 PMID: 14716538

42. Paraiso MF, Jelovsek JE, Frick A, Chen CC, Barber MD. Laparoscopic compared with robotic sacrocolpopexy for vaginal prolapse: a randomized controlled trial. Obstet Gynecol. 2011; 118: 1005–13. https://doi.org/10.1097/AOG.0b013e318231537c PMID: 21979458

43. Paraiso MF, Ridgeway B, Park AJ, Jelovsek JE, Barber MD, Falcone T, et al. A randomized trial comparing conventional and robotically assisted total laparoscopic hysterectomy. Am J Obstet Gynecol. 2013; 208: 368 e1–7.

44. Park JS, Choi GS, Park SY, Kim HJ, Ryuk JP. Randomized clinical trial of robot-assisted versus standard laparoscopic right colectomy. Br J Surg. 2012; 99: 1219–26. https://doi.org/10.1002/bjs.8841 PMID: 22864881

45. Patriti A, Ceccarelli G, Bartoli A, Spaziani A, Biancafarina A, Casciola L. Short- and medium-term outcome of robot-assisted and traditional laparoscopic rectal resection. JSLS. 2009; 13: 176–83. PMID: 19660212

46. Pietrabissa A, Pugliese L, Vinci A, Peri A, Tinozzi FP, Cavazzi E, et al. Short-term outcomes of single-site robotic cholecystectomy versus four-port laparoscopic cholecystectomy: a prospective, randomized, double-blind trial. Surg Endosc. 2016; 30: 3089–97. https://doi.org/10.1007/s00464-015-4601-3 PMID: 26497946

47. Porpiglia F, Morra I, Lucci Chiarissi M, Manfredi M, Mele F, Grande S, et al. Randomised controlled trial comparing laparoscopic and robot-assisted radical prostatectomy. Eur Urol. 2013; 63: 606–14. https://doi.org/10.1016/j.eururo.2012.07.007 PMID: 22840353

48. Sanchez BR, Mohr CJ, Morton JM, Safadi BY, Alami RS, Curet MJ. Comparison of totally robotic laparoscopic Roux-en-Y gastric bypass and traditional laparoscopic Roux-en-Y gastric bypass. Surg Obes Relat Dis. 2005; 1: 549–54. https://doi.org/10.1016/j.soard.2005.08.008 PMID: 16925289

49. Martinez-Maestre MA, Gambadauro P, Gonzalez-Cejudo C, Torrejon R. Total laparoscopic hysterectomy with and without robotic assistance: a prospective controlled study. Surg Innov. 2014; 21: 250–5. https://doi.org/10.1177/1553350613492023 PMID: 23833240

50. Roh HF, Kim J, Nam SH, Kim JM. Pulmonary resection for patients with multidrug-resistant tuberculosis based on survival outcomes: a systematic review and meta-analysis. Eur J Cardiothorac Surg. 2017; 52: 673–8. https://doi.org/10.1093/ejcts/ezx209 PMID: 29156011

51. Callewaert G, Bosteels J, Housmans S, Verguts J, Van Cleynenbreugel B, Van der Aa F, et al. Laparoscopic versus robotic-assisted sacrocolpopexy for pelvic organ prolapse: a systematic review. Gynecol Surg. 2016; 13: 115–23. https://doi.org/10.1007/s10397-016-0930-z PMID: 27226787

52. Huang X, Wang L, Zheng X, Wang X. Comparison of perioperative, functional, and oncologic outcomes between standard laparoscopic and robotic-assisted radical prostatectomy: a systemic review and meta-analysis. Surg Endosc. 2017; 31: 1045–60. https://doi.org/10.1007/s00464-016-5125-1 PMID: 27444830

53. Lee SH, Lim S, Kim JH, Lee KY. Robotic versus conventional laparoscopic surgery for rectal cancer: systematic review and meta-analysis. Ann Surg Treat Res. 2015; 89: 190–201. https://doi.org/10.4174/astr.2015.89.4.190 PMID: 26448918

54. Lim S, Kim JH, Baek SJ, Kim SH, Lee SH. Comparison of perioperative and short-term outcomes between robotic and conventional laparoscopic surgery for colonic cancer: a systematic review and meta-analysis. Ann Surg Treat Res. 2016; 90: 328–39. https://doi.org/10.4174/astr.2016.90.6.328 PMID: 27274509

55. Liu H, Lawrie TA, Lu D, Song H, Wang L, Shi G. Robot-assisted surgery in gynaecology. Cochrane Database Syst Rev. 2014: CD011422. https://doi.org/10.1002/14651858.CD011422 PMID: 25493418

56. Sandoval Salinas C, Gonzalez Rangel AL, Catano Catano JG, Fuentes Pachon JC, Castillo Londono JS. Efficacy of robotic-assisted prostatectomy in localized prostate cancer: a systematic review of clinical trials. Adv Urol. 2013; 2013: 105651. https://doi.org/10.1155/2013/105651 PMID: 24312127

57. Xiong B, Ma L, Zhang C. Robotic versus laparoscopic gastrectomy for gastric cancer: a meta-analysis of short outcomes. Surg Oncol. 2012; 21: 274–80. https://doi.org/10.1016/j.suronc.2012.05.004 PMID: 22789391

58. Asimakopoulos AD, Pereira Fraga C.T., Annino F., Pasqualetti P., Calado A.A., Mugnier C. Randomized comparison between laparoscopic and robot-assisted nerve-sparing radical prostatectomy. Journal of Sexual Medicine. 2011.

59. Finkelstein J, Eckersberger E, Sadri H, Taneja SS, Lepor H, Djavan B. Open Versus Laparoscopic Versus Robot-Assisted Laparoscopic Prostatectomy: The European and US Experience. Rev Urol. 2010; 12: 35–43. PMID: 20428292