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REVIEW ARTICLE

The robotic single-port platform for gynecologic surgery: a systematic review of the literature and meta-analysis

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Abstract

Since the first robotic single-site hysterectomy was performed, the research focused on the use of robotic single-site surgery (RSSS) for all gynecological conditions. This review aims to examine the studies available in the literature on RSSS in gynecology both for benign and malignant indications. The systematic review was carried out in agreement with the preferred reporting items for systematic reviews and meta-analyses statement (PRISMA). All the articles were grouped into three sets based on the surgical indication (Group 1, 2, and 3 for benign, malignant, and mixed diseases, respectively). Two hundred and fifty total studies were analyzed, and 27 articles were included in the review. A total of 1065 patients were included in the analysis. Of these, 605 patients were included in group 1, 260 in group 2, and 200 in group 3. Ten (1.7%) patients with benign pathology, 16 (6.2%) patients with malignant disease, and 5 (2.5%) patients with both diseases developed major complications. Two (0.3%) patients in group 1, 3 (1.2%) patients in group 2 and 5 (2.5%) in group 3 were converted to a different type of surgery. No significant differences were found between groups for BMI ($p=0.235$), operative time ($p=0.723$), estimated blood loss (EBL) ($p=0.342$), and hospital stay ($p=0.146$). The complications and conversions incidence through pooled analysis showed a higher general conversion rate ($p=0.012$) in group 3 (3.0%) and higher complications rate ($p=0.001$) in group 2 (5.3%) compared to the other groups. RSSS seems to be a feasible and safe procedure for all gynecological surgical procedures. A long-term analysis would be necessary before considering the RSSS oncologically safe for patients with malignant disease.

Keywords Robotic single-site surgery · Hysterectomy · Gynecological surgery · Complications · Outcomes

Introduction

The surgical technological innovation in different surgical fields, including gynecology, allowed to improve the surgical outcomes [1, 2], reducing the complication rate and the aesthetic impact [3–9]. Several ultra-minimally invasive technologies are suitable to reduce the invasiveness of standard laparoscopic surgery [10–17]. Compared to the different techniques available, single-site surgery acquired relevance in the gynecologic surgical field, since the access to the abdominal cavity was obtained through a single 20–30 mm transumbilical port. However, some limitations have been reported, such as the absence of triangulation, the reduction of surgical dexterity, and consequently, a prolonged surgical time [18, 19]. The ultra-minimally invasive surgery has been directed towards a more sophisticated technology designed to reduce the number and extent of skin incisions required. New surgical robotic platforms are available with the aim of overcoming the limits of laparoscopy [20–26]. The single-site robotic platform allows the surgeon to achieve remarkable ergonomic comfort, overcoming flexible or clashing instruments, as in the case of single-site laparoscopy. In this context, the single-site robotic platform acquired importance in the field of ultra-minimally invasive surgery.

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Table 1 Characteristics of included studies

Authors, years	Type of study	Cases number	Surgery	Condition	Operative time (min)	Ebl (ml)	Conversion rate	Hospital stay (day)	Complication number/type	Outcomes	BMI median	Robot
Chung et al. [39]	Retrospective study	15	Hysterectomy, salpingo-oophorectomy, bilateral pelvic node dissection	Endometrial cancer	155	145	0	3	1 1 Incisional hernia	RSSS is feasible and safe	25.4	Da Vinci Si® surgical system
Liu et al. [48]	Retrospective study	15	Sacrocolpopexy with total or supracervical hysterectomy was completed	Pelvic organs prolapse	74.7	–	0	–	0	RSSS is feasible and safe	27	Da Vinci Si® surgical system
Moon et al. [51]	Retrospective cohort study	68	Cystectomy and adhesiolysis	Advanced-stage endometriosis	107.8	107	0	4.6	0	RSSS surgery can be used	23.1	Da Vinci Si® surgical system
Kliethermes et al. [46]	Prospective cohort study	29	Hysterectomy	Benign indications	152	70	0	–	0	RSSS have less postoperative pain respect to robotic multiport surgery	29.07	–
Jayakumaran et al. [44]	Retrospective cohort study	35	Hysterectomy with or without salpingo-oophorectomy	Benign indications	59	75	2	1	1 1 Cystotomy	RSSS is feasible and safe	27	Da Vinci Si® surgical system
Moukarzel et al. [52]	Retrospective cohort study	14	Hysterectomy with sentinel lymph node mapping	Low-risk endometrial cancer	175	50	0	–	0	RSSS is cheaper than robotic multiport surgery	24.6	Da Vinci Si® surgical system

Table 1 (continued)

Authors, years	Type of study	Cases number	Surgery	Condition	Operative time (min)	Ebl (ml)	Conversion rate	Hospital stay (day)	Complication number/type	Outcomes	BMI median	Robot
de Meritens et al. [59]	Retrospective cohort study	83	Hysterectomy with/without pelvic lymph node biopsy	Either benign or malignant	128	45	1	0.5	2 2 Umbilical hernias	RSSS have improved cosmesis and less perioperative pain compared to standard approaches	25.9	Da Vinci Si® surgical system
Moukarzel et al. [22]	Retrospective study	30	Hysterectomy	Gynecologic malignancies	140	86	1	–	0	RSSS is associated with acceptable operative times and perioperative outcomes	26	Da Vinci Si® surgical system
Gargiulo et al. [42]	Retrospective cohort study	21	Myomectomy	Benign indications	154.2	57.9	0	0.6	3 2 Small bowel obstruction 1 Superficial cellulitis	RSSS offers excellent cosmetic and postoperative outcomes	29.4	Da Vinci Si® surgical system
Paek et al. [53]	Retrospective cohort study	25	Hysterectomy	Benign indications	170.9	20	0	3.5	0	RSSS is feasible and safe	24.3	Da Vinci Si® surgical system
Akdemir et al. [35]	Retrospective cohort study	24	Hysterectomy	Benign indications	98.5	22.5	0	1.6	0	RSSS is safe and feasible	28.5	Da Vinci Si® surgical system
Scheib et al. [55]	Prospective study	40	Hysterectomy or adnexal surgery	Either benign or malignant	134	50	3	0.5	3 1 Bowel obstruction 1 Cuff cellulitis 1 Vaginal cuff defect	RSSS is feasible and safe	28.2	Da Vinci Si® surgical system
Sendag et al. [56]	Retrospective study	24	Hysterectomy	Benign indications	98.5	22.5	0	1	0	RSSS is feasible and safe	28.5	Da Vinci Si® surgical system
Cela et al. [37]	Retrospective study	12	Hysterectomy	Either benign or malignant	170	80	0	2	0	RSSS is feasible and safe	26	Da Vinci Si® surgical system

Table 1 (continued)

Authors, years	Type of study	Cases number	Surgery	Condition	Operative time (min)	Ebl (ml)	Conversion rate	Hospital stay (day)	Complication number/type	Outcomes	BMI median	Robot
Corrado et al. [40]	Prospective study	125	Hysterectomy with or without pelvic lymphadenectomy	Endometrial cancer	122	50	1	2	10 2 Pelvic bleeding 2 Wound infection 2 Cystitis 1 Fever 1 1 Deep vein thrombosis 1 Vaginal vault hematoma 1 Lower limbs neuropathy	RSSS is technically feasible, safe and reproducible	27	Da Vinci Si® surgical system
Gungor et al. [43]	Retrospective cohort study	20	Hysterectomy	Either benign or malignant	147.5	40	0	1	0	RSSS is feasible and safe	28.7	Da Vinci Si® surgical system
Matanes et al. [49]	Retrospective study	25	Sacrocolpopexy	Benign indications	190	50	0	2	1 1 Small bowel obstruction	RSSS is a feasible with low complication rates	26	Da Vinci Si® surgical system
Bogliolo et al. [30]	Retrospective study	45	Hysterectomy and bilateral salpingo oophorectomy	Benign indications	144	46	0	1.5	1 1 not specified	RSSS is effective, safe and with a potential cost reduction versus robotic multiport surgery	25	Da Vinci Si® surgical system
Paek et al. [53]	Retrospective cohort study	20	Salpingo-oophorectomy and ovarian cystectomy	Ovarian tumour	91.1	20	0	2.3	0	RSSS could be performed safely without complications or additional port insertion	22.7	Da Vinci Si® surgical system

Table 1 (continued)

Authors, years	Type of study	Cases number	Surgery	Condition	Operative time (min)	Ebl (ml)	Conversion rate	Hospital stay (day)	Complication number/type	Outcomes	BMI median	Robot
Bogliolo et al. [36]	Retrospective study	45	Hysterectomy	Either benign or malignant	134	53	1	2.7	2 1 Haemoperitoneum 1 Vaginal cuff hematoma	RSSS is feasible and safe, allows optimal postoperative pain control and improved cosmetic results	25	Da Vinci Si® surgical system
Fagotti et al. [41]	Retrospective case control study	19	Hysterectomy	Endometrial cancer	90	75	0	2	1 1 Hemoperitoneum	RSSS is feasible and safe	26	Da Vinci Si® surgical system
Choi et al. [38]	Retrospective analysis	61	Myomectomy	Myomas	136	183	0	4.2	0	RSSS is feasible and safe	-	Da Vinci Si® surgical system
Vizza et al. [58]	Prospective cohort trial	17	Hysterectomy	Endometrial cancer	90	75	1	2	0	RSSS is technically feasible	26.6	Da Vinci Si® surgical system
Vizza et al. [57]	prospective cohort trial	20	Radical hysterectomy plus pelvic lymphadenectomy	Endometrial or cervical cancer	190	75	0	6	4 1 Pelvic abscess 1 Lymphorrhea 1 Bowel perforation 1 Vaginal dehiscence	RSSS is technically feasible	23.5	Da Vinci Si® surgical system
Lauterbach et al. [47]	Retrospective study	52	Sacrocervicopexy	Apical prolapse	187.8	20	0	2.7	2 2 Hematoma	RSSS is feasible and the short-term outcomes and learning curves are comparable to robotic multisite surgery	27.8	Da Vinci Si® surgical system

Table 1 (continued)

Authors, years	Type of study	Cases number	Surgery	Condition	Operative time (min)	Ebl (ml)	Conversion rate	Hospital stay (day)	Complication number/type	Outcomes	BMI median	Robot
Moawad et al. [50]	Multicenter retrospective study	80	Myomectomy	Myomas	162.4	83.3	0	1.1	2 2 Incision haematoma	RSSS is equivalent to its multiport counterpart	25.3	Da Vinci Si® surgical system
Kim et al. [45]	Retrospective study	101	Myopmectomy	Myomas	144.5	201.6	0	5	0	RSSS is a feasible	21.5	Da Vinci Si® surgical system

RSSS robotic single site surgery

Since Fader performed the first robotic single-site hysterectomy, the research has focused on using robotic single-site surgery (RSSS) for all gynecological conditions, both malignant and benign [27], showing better practicality in intracorporeal sutures with an acceptable learning curve due to the characteristics of the surgical arms compared to the classic laparoscopy [28].

Several studies in the literature have demonstrated the excellent surgical success and aesthetic outcome related to RSSS with similar complication rates compared to traditional surgery [29]. A recent analysis considers RSSS more cost-effective than robotic multi-site surgery [30]. Furthermore, RSSS is also associated with a lower hospital stay, less post-operative pain, and better patient satisfaction compared to multi-site techniques [31]. All these benefits allowed this new technology to spread rapidly in different surgeries [32].

This review aims to examine the studies available in the literature on RSSS in gynecology both for benign and malignant indications in terms of operative outcomes.

Methods

In June 2019, a systematic review of the literature was done on Pubmed, Scopus, and Google Scholar search engines.

We searched for the following keywords: "robotic single-site surgery and Gynecology", "robotic single port surgery and Gynecology", "robotic single-incision surgery and Gynecology", "robotic laparoendoscopic single-site surgery and Gynecology".

The systematic review was carried out in agreement with the preferred reporting items for systematic reviews and meta-analyzes statement (PRISMA) [33]. Two independent authors (CVA and AG) double-checked the research to exclude repeated articles. Articles with non-English language, case reports, reviews, case series with less than 10 cases were excluded. All relevant studies cited by the selected papers were also included in the analysis. Of all the studies we reported the type of surgery, surgical indication, operative time, complications, cases with conversion to other surgery types, EBL, BMI, and type of robot used (Table 1).

We divided the studies into 3 groups, according to the type of condition included: group 1 including only cases with benign pathology, group 2 studies with only malignant disease patients, and group 3 including both. Any surgical modification to the RSSS, from the placement of an additional trocar to the open surgery, was considered as a surgical conversion.

For the complication rate, we considered the common terminology criteria for adverse events (CTCAE) grade ≥ 3 [34]. All parameters are expressed in median and percentage.

Statistical analysis

Data were displayed as standard deviation (SD) or as number (percentage). Categorical variables were compared using the Chi-square or Fisher exact test. Between-group comparison of continuous variables was undertaken using the *t* test and the Mann–Whitney nonparametric equivalent test. Two-sided p-values were calculated, and p values < 0.05 were considered as statistically significant. Comparisons between > 2 groups were performed using the Kruskal–Wallis test or ANOVA when appropriate. Meta-analyses of proportions were used to combine data. Between-study heterogeneity was explored using the I^2 statistic, which indicates the percentage of between-study variation that is due to heterogeneity rather than chance. A value of I^2 of 0% indicates no observed heterogeneity, whereas values $\geq 50\%$ indicate a substantial level of heterogeneity. Given the small sample size of the included studies, a random effect model was preferred, regardless of I^2. StatsDirect 3.0.17 (StatsDirect Ltd, Altrincham) statistical software was used for all data analyses.

Results

Two hundred and fifty total studies were obtained by searching for keywords; 103 with 'robotic single-site surgery and Gynecology', 61 with 'robotic single PORT surgery and Gynecology', 47 with robotic single-incision

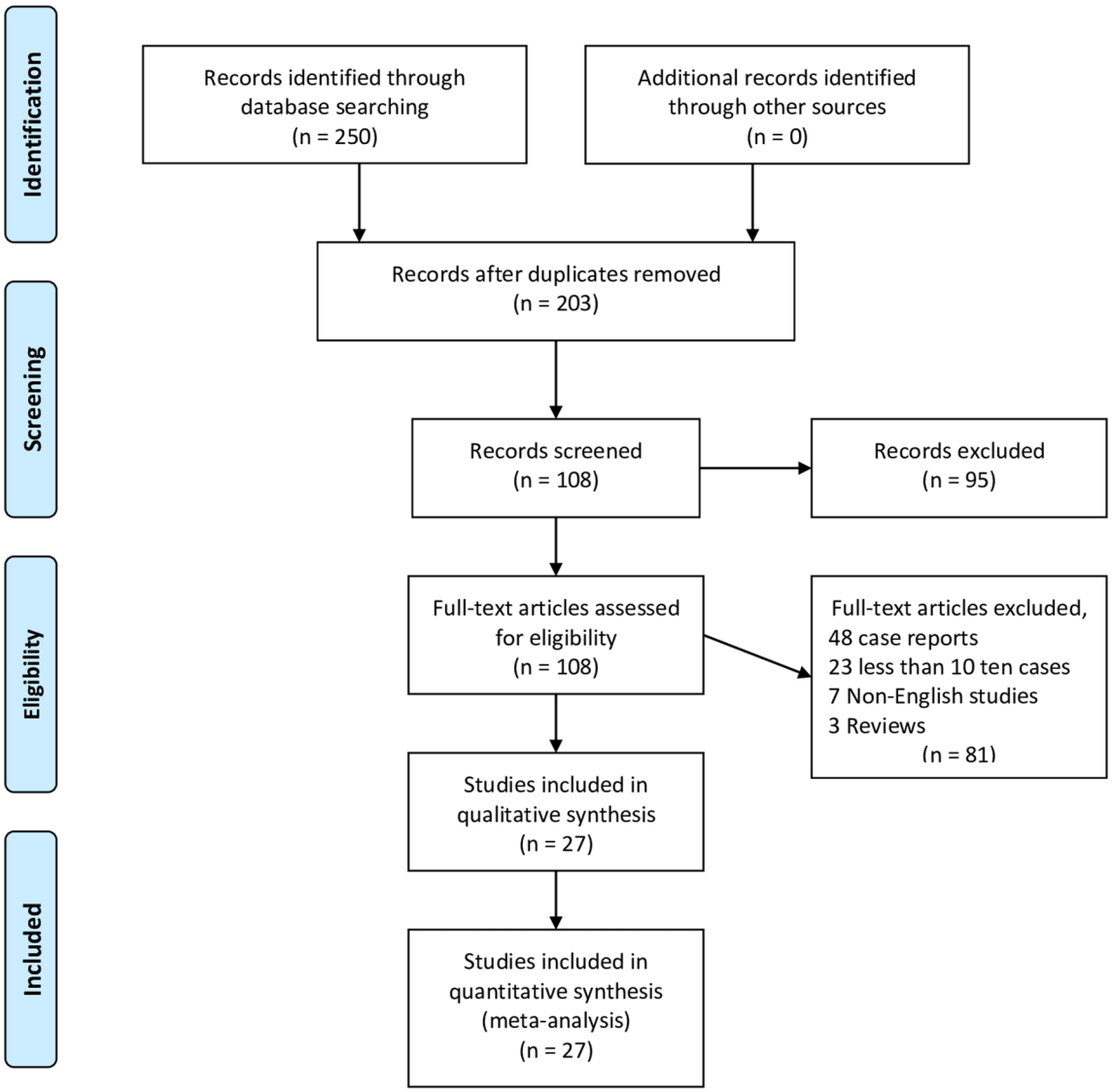

Fig. 1 Flow-chart of the included studies

surgery and Gynecology, and 39 with 'robotic laparoendoscopic single-site surgery and Gynecology' respectively. With the removal of the duplicate articles and screening all the articles with the selection criteria, 27 articles were included in the review [22, 30, 35–59]. PRISMA flow chart is shown in Fig. 1.

Fourteen studies were included in (group 1) [30, 35, 38, 42, 44–51, 53, 56], eight (in group 2) [22, 39–41, 52, 54, 57, 58], and five articles (in group 3) [36, 37, 43, 55, 59], with 605, 260, and 200 cases respectively. The results are reported in Table 2. The median BMI was 27, 25.7, and 26 in groups 1, 2, and 3, respectively. The median of the operative times was 144.3 min for studies including only benign pathologies, 131 min for those including only malignant pathologies, and 134 min for those including both. The median estimated blood loss (EBL) was 57.9 ml, 75 ml, and 50 ml in groups 1, 2, and 3, respectively. Two (0.3%) patients in the group 1, 3 (1.2%) patients in group 2 of malignancies, and 5 (2.5%) in group 3 were converted. Five cases of multiport robotic surgery, two classic laparoscopy, two necessary additional port cases, and one vaginal surgery as conversion types have been reported in the three groups.

The median length of stay was 1.8 days for group 1, 2.2 days for group 2, and 1.0 day for group 3, respectively. Ten (1.7%) patients in the benign pathology group, 16 (6.2%) patients with malignant disease, 5 (2.5%) patients with both benign and malignant disease developed major complications. As shown in Table 1, eight vascular, eight intestinal, five vaginal, four infectious, three urinary, one thrombotic, one nervous, one lymphatic complication has been reported in the three groups.

No significant differences were found between groups for BMI ($p=0.235$), operative time ($p=0.723$), EBL ($p=0.342$), and hospital stay ($p=0.146$). The complications and conversions incidence through pooled analysis showed a higher general conversion rate ($p=0.012$) in group 3 (3.0%) and higher complications rate ($p=0.001$) in group 2 (5.3%) compared to the other groups (Fig. 2).

In all the studies selected, the Da Vinci Si® surgical system (Intuitive Surgical, Sunnyvale, CA, USA) was used.

Discussion

The single-site robotic platform represents today an impressive and evolving technology. The field of ultra-minimally invasive surgery aimed to reduce the surgical and aesthetic impact, maintaining the same procedural complexity. The reduction of invasiveness is one of the main factors to improve the quality of life of patients, [60–65].

In the study by Chung et al., two critical steps during surgery are reported: lymphadenectomy in patients with malignant disease and, more generally, the vaginal cuff closure [39]. According to the same authors, lymphadenectomy requires a long learning curve, while the difficulty of the vaginal cuff closure could be overcome by replacing the classic curved needle with a straight one [39].

The main advantage of this technique performed by robotics is to overcome the ergonomic limitations and the absence of a triangulation of single-site laparoscopy [32]. Furthermore, the amplification of precise movement and availability of three-dimensional vision should also be considered as factors improving the surgical performance and outcomes. Robotic surgery also allows the so-called 'chopstick effect' of single-site laparoscopic surgery to be overcome. In particular, the nearness of the laparoscopic instruments, causes a mechanical conflict between the surgeons' hands, making the surgery less ergonomic. The robotic arms, thanks to their articulation, allow us to avoid this limitation. Furthermore, the robotic system allows the instruments to cross inside the abdominal cavity, rather than crossing surgeons' hands As reported in a recent meta-analysis, the presence of last technological innovation as the EndoWrists, allowed to perform a more precise procedure, improving especially the knotting times [32].

Table 2 The studies were grouped according to the patients' pathology

	Benign indication $n=605$	Malignant indication $n=260$	Mixed indication $n=200$	p value
Number of studies	14	8	5	
Operative time	144.3	131	134	0.723
Ebl	57.9	75	50	0.342
Conversion	2 (0.3)	3 (1.2)	5 (2.5)	0.012
Hospital stay	1.8	2.2	1.0	0.146
Complication	10 (1.7)	16 (6.2)	5 (2.5)	0.001
BMI	27	25.7	26	0.235

Group 1 benign indication, *Group* 2 malignant indication, *Group* 3 either benign or malignant indication

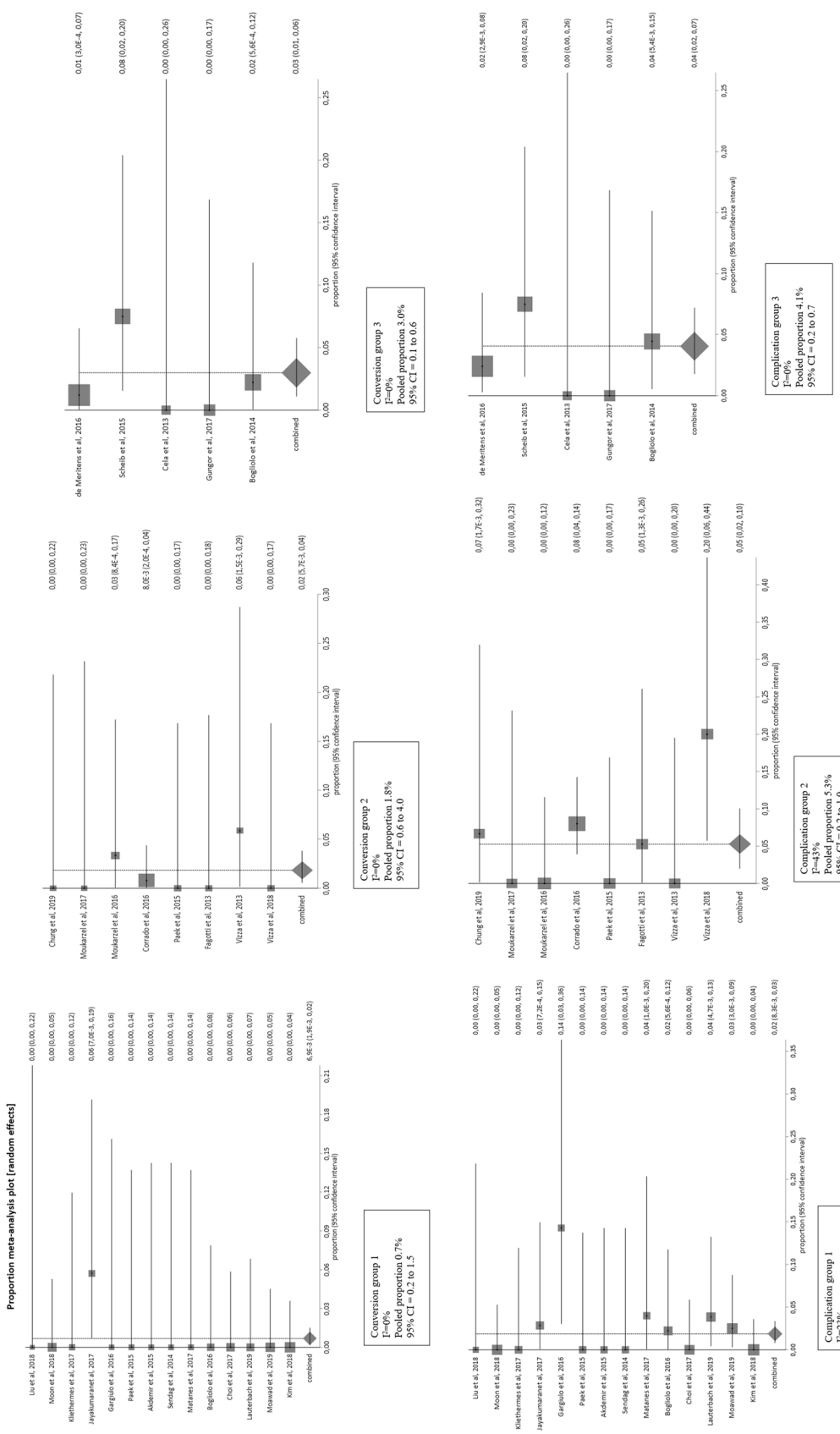

Fig. 2 Pooled proportion of conversion and complications among the three groups

The angle of the surgical arms is a particularly important aspect, even in case of small precision surgery. As reported by Moon et al., the angulation of the instruments through the Da Vinci platform allows putting the instruments in a plane tangent to the surgical object, allowing an optimal approach [51].

Despite its advantages, RSSS remains a complex surgery requiring a long learning curve.

Our study shows that patients with malignant disease had a higher complication rate than patients with benign disease 5.3% vs. 1.9%, respectively.

In the case of malignant disease, complex procedures are described, such as lymphadenectomy or radical hysterectomy, with a higher burden of complications than benign surgery. As a consequence, we have observed a longer average hospital stay in group 2, even if not statistically significant.

Finally, we have found a higher conversion rate for group 3 than for the other two groups (3.0% vs. 0.7 and 1.8, respectively). In our opinion, this result is of little significance because in the studies included in the analysis there was no agreement on the definition of surgical conversion; moreover, this result could be influenced by the surgeon's expertise, not clearly homogeneous among groups.

In fact, for some authors, the conversion was considered as the addition of a single trocar, whereas for others it was defined as the transition from minimally-invasive to open surgery. The most frequently reported complications in the RSSS are the ones involving the bowel, and those related to the vaginal cuff closure. In the five bowel complications, only one required reoperation for bowel perforation, whereas the other four were simple intestinal obstructions. In the five vaginal complications, three cuff dehiscences required a reoperation, whereas two hematomas resolved by conservative treatment. The remaining complications reported in Table 1, from surgical site infection to urinary complications, were grade 2, according to the common terminology criteria for adverse events (CTCAE) [34], in line with the adverse events of classical minimally invasive gynecological surgery. In particular, the wound infection rate and the incidence of incisional hernia are probably related to a more extensive umbilical incision needed in the RSSS.

This study presents some limitations, mainly depending on the heterogeneity of the studies included, on the retrospective nature of most of the articles included, and on the limited number of cases reported in some of them. Despite this, the pooled analysis shows a low heterogeneity of the studies (I^2 statistic test always < 50%).

To the best of our knowledge, this is the first analysis of the RSSS outcomes concerning the different surgical indications in the literature. In light of these considerations, technological innovations, as for benign and malignant pathologies, are aimed to improve the outcomes and the quality of life [66–69]. These considerations also apply to other non-gynecological diseases [70, 71].

Even if a comprehensive investigation of patients' characteristics remains a fundamental part, the single-site robotic platform represents a single step toward this aspect, but some potential improvements are possible.

Conclusion

RSSS seems to be a feasible and safe technique for all gynecological surgical procedures. There are no significant differences in terms of operative time, estimated blood loss, and hospital stay when approaching to either malignant or benign conditions by RSSS. The higher complication rate for RSSS in malignant group is in line with the complications of traditional surgery for malignant conditions.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Research involving human participants and/or animals This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent is not required for this type of study.

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