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Review

'Money for nothing' ☆. The role of robotic-assisted laparoscopy for the treatment of endometriosis

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KEY MESSAGE

Robotic-assisted laparoscopic treatment of endometriosis does not provide benefits over standard laparoscopy. Because the quality of published studies is low, randomized studies comparing robotic and standard laparoscopy for endometriosis are needed. At present, due to the increased costs, robotic surgery may not be justified outside of research settings.

A B S T R A C T

Despite higher costs for robotic-assisted laparoscopy (RAL) than standard laparoscopy (SL), RAL treatment of endometriosis is performed without established indications. PubMed/MEDLINE was searched for 'robotic surgery' and 'endometriosis' or 'gynaecological benign disease' from January 2000 to December 2016. Full-length studies in English reporting original data were considered. Among 178 articles retrieved, 17 were eligible: 11 non-comparative (RAL only) and six comparative (RAL versus SL). Non-comparative studies included 445 patients. Mean operating time, blood loss and hospital stay were 226 min, 168 ml and 4 days. Major complications and laparotomy conversions were 3.1% and 1.3%. Eight studies reported pain improvement at 15-month follow-up. Comparative studies were all retrospective; 749 women underwent RAL and 705 SL. Operating time was longer for RAL in five studies. Major complications and laparotomy conversions for RAL and SL were 1.5% versus 0.3% and 0.3% versus 0.5%. One study reported pain reduction for RAL at 6-month follow-up. RAL treatment of endometriosis did not provide benefits over SL, overall and among subgroups of women with severe endometriosis, peritoneal endometriosis and obesity. Available evidence is low-quality, and data regarding long-term pain relief and pregnancy rates are lacking. RAL treatment of endometriosis should be performed only within controlled studies.

☆ Dire Straits: Brothers in arms. Warner Bros. Records, London/New York 1985.

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Table 1 – Potential advantages and drawbacks of robotic-assisted laparoscopy for the surgical treatment of endometriosis.

Advantages	Drawbacks
Higher degree of freedom in the robotic instrument and reduction in tremor interference	Cost of implementation and maintenance
Three-dimensional vision	Inability to move the surgical table once the robot arms are attached and inability to operate in different quadrants at the same time
Motion scaling	Lack of tactile feedback to the surgeon
Ambidextrous capability	Time required to dock and separate the robotic cart from the patient
Better ergonomics (the ability of the surgeon to sit)	Large sized ports (8 mm)
Telesurgery	

Introduction

During the last decades, laparoscopic surgery has been accepted as the technique of choice for the treatment of endometriosis, because it provides long-term outcomes comparable to those achieved by laparotomy, with the established advantages of a minimally invasive technique, including better visualization, shorter hospital stay, faster recovery and better cosmetic results (Adamson et al., 1992; Daraï et al., 2010; Luciano et al., 1992; Vercellini et al., 2003).

More recently, robotic-assisted laparoscopy (RAL) has become available, which is an implementation of standard laparoscopy (SL). The technical advantages and disadvantages of RAL compared with SL are reported in **Table 1**. Briefly, the main advantages of RAL over SL include the availability of articulating instruments capable of a range of movements comparable to those of the human wrist, and the possibility of reducing or eliminating the surgeon's tremor, whereas the major disadvantage of RAL is a reduced overall versatility compared with SL.

When comparing RAL and SL, the issue of costs is also of paramount importance, as the former technique is more expensive than the latter one. Expenses for RAL are related to the cost of around 2 million euros for the robot itself, the annual maintenance fee of around 160,000 euros and the cost of 1200 to 2000 euros of each robotic instrument, which must be mandatorily replaced after 10 surgical procedures (Paul et al., 2013; Trehan and Dunn, 2013). Consequently, in order to justify a widespread use of a more expensive technique such as RAL, this technique has to prove advantageous over SL in terms of better outcomes for the patients.

Although several studies have reported the use of RAL for the treatment of endometriosis, the specific clinical indications for RAL rather than SL, and the practical advantages for the patients of the former choice, are not yet established. This study sought to perform a review of the available evidence in order to possibly clarify the issue of whether women with endometriosis, or specific subgroups of patients with the disease, may benefit from RAL compared with SL.

Materials and methods

The present review was conducted according to the PRISMA guidelines for systematic reviews (Moher *et al.*, 2010). The quality of evidence of the selected studies was further assessed using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) criteria (Guyatt *et al.*, 2008). As only published data were used, the present study was exempt from Institutional Review Board approval.

Sources

This review was restricted to published research articles that reported the use of RAL for the treatment of endometriosis or specific subgroups of patients with the disease. A PubMed/MEDLINE search was performed of papers published between January 2000 and December 2016, using the terms 'robotic surgery' combined with 'endometriosis' or 'gynaecological benign disease'. Only studies published as full-length in English and reporting original data were included. All pertinent articles and review articles were retrieved and their bibliographies were systematically examined to identify any other relevant publication that could be included. Only published data were used and no attempt was made to identify unpublished studies.

Study selection and data extraction

Three authors (MPF, MF and LB) conducted an independent screening of all titles and abstracts retrieved from peer-reviewed journals to exclude irrelevant or duplicate citations. Data presented exclusively as abstracts in national and international meetings, or case reports or articles including less than five women or review articles that did not include original data were excluded. When more than one publication based on the same study population and data was found, only the one with most detailed information, or published most recently was included.

Two authors (MPF and MF) designed a data extraction form that was applied to each paper to independently extract data regarding authors, year of publication, country, study design, number of recruited subjects, age of participants, body mass index (BMI), previous surgery, type of surgical treatment, operating time, blood loss, hospital stay, length of follow-up, major complications, postoperative pain and pregnancy rate. Studies were categorized based on research design as prospective, retrospective, comparative and non-comparative. Correction or resolution of any discrepancies between reviewers was reached by consensus after discussion or arbitration by a third reviewer (NB).

Results

The flow diagram of the literature search results is shown in **Figure 1**. Because almost all studies included in this review are observational studies, the final assessment according to the GRADE criteria (Guyatt *et al.*, 2008), was a low level of quality. One-hundred and forty-three articles were identified by database search as potentially relevant, and other 35 citations were identified from reference lists. Among the 178 articles, 156 were excluded after evaluation of the abstract and full text because they did not satisfy the inclusion criteria, and 22 articles were assessed for eligibility. Another five publications were excluded from the current review. One study (Vitobello et al., 2013) was excluded because enrolled patients were most likely included in a larger, more recent study from the same group (Siesto et al., 2014). Two studies were excluded because the number of patients with

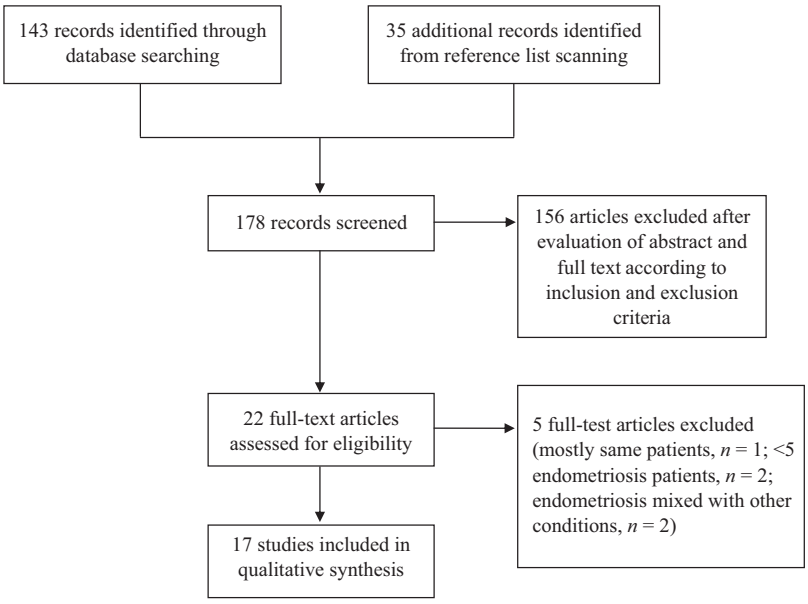

Figure 1 – Flowchart of the study selection process.

endometriosis was <5 (Tan et al., 2012; Williams and Leveillee, 2009). Two studies were excluded because it was not possible to separate surgical data relative specifically to the treatment of endometriosis from those relative to other gynaecological conditions (Scheib and Fader, 2015; Smorgick et al., 2012). Complete author agreement regarding included and excluded studies was achieved.

Seventeen studies were eventually selected. Among them, 11 studies were non-comparative, i.e. included women operated with RAL only (Abo et al., 2016; Bedaiwy et al., 2013; Brudie et al., 2012; Collinet et al., 2014; Ercoli et al., 2012; Lim et al., 2011; Morelli et al., 2016; Neme et al., 2013; Nezhat et al., 2011; Pellegrino et al., 2015; Siesto et al., 2014), whereas six studies were comparative, i.e. compared two series of women operated with RAL and SL (Cassini et al., 2014; Dulemba et al., 2013; Magrina et al., 2015; Nezhat et al., 2010, 2015; Nezhat and Sirota, 2014). None of these comparative studies was a randomized trial.

Non-comparative studies

The characteristics of the patients and the perioperative data of the non-comparative studies are reported in **Table 2**. Four studies were prospective (Abo et al., 2016; Lim et al., 2011; Neme et al., 2013; Pellegrino et al., 2015) and seven were retrospective (Bedaiwy et al., 2013; Brudie et al., 2012; Collinet et al., 2014; Ercoli et al., 2012; Morelli et al., 2016; Nezhat et al., 2011; Siesto et al., 2014). In total, 445 patients were evaluated, with a mean age of 39 years. The most frequent indication for RAL was deep infiltrating endometriosis: 55% of women underwent excision of bowel endometriosis, 27% ureterolysis and 8% excision of urinary tract endometriosis. Thirty-six percent of women underwent hysterectomy in addition to excision of endometriotic lesions. Mean operating time was 226 min, mean blood loss was 168 ml and mean hospital stay was 4 days. The outcome of the surgical procedures performed in non-comparative studies are reported in **Table 3**. The rate of major complications was 3.1%, with a 1.3% rate of conversion to laparotomy. All the eight studies that evaluated the effect of surgery on symptoms (Abo et al., 2016; Brudie et al., 2012; Collinet et al., 2014; Ercoli et al., 2012; Morelli et al., 2016; Neme et al., 2013; Nezhat et al., 2011; Siesto et al., 2014), with a mean follow-up time of 15 months (range 2–28 months), reported either complete remission or a significant reduction of pain. The mean pregnancy rate among 73 women wishing to conceive in five studies was 38% at a mean follow-up of 16 months (range 10–24 months). One study reported that sexual wellbeing, urinary function and impact of symptoms on quality of life were slightly worsened 1 month after surgery, and became comparable to the preoperative period 1 year after surgery. Dyspareunia was the only exception, as it was significantly improved 12 months after surgery (Morelli et al., 2016).

Comparative studies

All studies were retrospective and included a total of 1454 women, 749 undergoing RAL and 705 SL. One study (Dulemba et al., 2013), included women who presented with pelvic pain suggestive of endometriosis; among them, endometriosis was eventually diagnosed in 78% of women in the RAL group and 71% of women in the SL group. The prevalence of advanced endometriosis, i.e. stage III or IV according to the revised American Society for Reproductive Medicine classification (ASRM, 1997), was 23% in one study (Nezhat et al., 2010), 48% in another study (Dulemba et al., 2013) and 100% in the remaining 4 studies. In all studies, the decision of performing RAL or SL was made upon preference of the surgeon and availability of the robot. A preoperative diagnosis of high-complexity cases favoured a RAL approach in two studies (Nezhat et al., 2015; Nezhat and Sirota, 2014), and obesity favoured a RAL approach in one study (Nezhat and Sirota, 2014).

In one study, patients in the two groups were not comparable because of the higher number of procedures and more radical operations in the robotic group (Magrina et al., 2015). In this study, women undergoing hysterectomy, colorectal shaving or disk excision, small bowel resection or ureteral surgery in the RAL group versus the SL group were 50% versus 27%, 2.7% versus 0.6%, 1.2% versus 1.2%

Table 2 – Characteristics of 11 non-comparative studies evaluating robotic-assisted laparoscopy for the treatment of moderate/severe and deeply infiltrating endometriosis. Literature data, 2011–2016.

Author, year	Number of patients	Study design	Age of patients	BMI of patients	Previous surgery	Bowel shaving/disc excision	Bowel resection	Bladder resection	Uretero-lysis	UNC	Hysterectomy	Operating time (min)	Blood loss (ml)	LOS (days)
	(number)		(mean or [b]median (years))		(number (%))							(mean or [b]median (range))		
Nezhat et al., 2011	5	R	38	NR	4 (80)	1 (20)	1 (20)	1 (20)	1 (20)	1 (20)	2 (40)	328 (245–475)	195 (100–350)	2
Lim et al., 2011	8	P	47	30	8 (100)	–	8 (100)	–	8 (100)	–	8 (100)	238 (157–321)	425 (50–1500)	6
Brudie et al., 2012	80	R	44	27,5	23 (29)	–	–	–	29 (36)	–	62 (78)	115 (69–161)	88 (21–155)	1
Ercoli et al., 2012	10	R	38[b]	21[b]	12/22 (55)[a]	10 (100)	–	–	–	–	–	280[b] (220–365)	200[b] (100–350)	5
Ercoli et al., 2012	12	R	38[b]	21[b]	12/22 (55)[a]	–	12 (100)	–	–	1 (8)	–	370[b] (260–720)	100[b] (50–250)	8
Bedaiwy et al., 2013	43	R	46[b]	28	9 (21)	–	–	–	–	–	43 (100)	190[b] (97–368)	100[b] (20–400)	1
Neme et al., 2013	10	P	37	23	5 (50)	–	10 (100)	–	8 (80)	–	–	157 (90–190)	NR	3
Collinet et al., 2014	164	R	34	24	39 (24)	68 (41)	24 (15)	22 13)	62 (38)	1 (1)	28 (17)	180 (103–257)	85 (5–2300)	4
Siesto et al., 2014	43	R	34[b]	22[b]	21 (49)	23 (53)	19 (44)	5 (12)	–	–	3 (7)	200[b] (57–366)	120[b] (100–1000)	3
Pellegrino et al., 2015	25	P	34	21	18 (72)	25 (100)	–	–	–	–	2 (8)	174[b] (75–300)	NR (0–100)	3
Abo et al., 2016	35	P	36	24,5	20 (57)	28 (80)	4 (11)	3 (9)	11 (31)	2 (6)	11 (31)	207 (NR)	NR	NR
Morelli et al., 2016	10	R	36[b]	22[b]	7 (70)	–	10 (100)	–	3 (30)	–	–	280[b] (180–420)	200 (100–400)	6
Total	445	–	39	24	179 (40)	155 (35)	88 (20)	31 (7)	122 (27)	5 (1)	159 (36)	226 (57–720)	168 (0–2300)	4

[a] In Ercoli et al. 2012, the number of patients who underwent previous surgery is not reported separately for the two subgroups.

Data from Ercoli et al. 2012 were reported separately for women who underwent bowel shaving (n = 10) and women who underwent bowel resection (n = 12).

Values are mean or [b]median (range), or number (%).

BMI = body mass index; LOS = length of hospital stay; NR = not reported; P = prospective; R = retrospective; UNC = uretero-neocystostomy.

Table 3 – Complications and outcome of women undergoing robotic-assisted laparoscopy for advanced endometriosis in 11 non-comparative studies. Literature data, 2011–2016.

Study	Follow up (months)	Major complications	Conversion to laparotomy	Postoperative pain (%)	Pregnancy rate[a]
	(mean)	number (%)			(number pregnant women/women seeking pregnancy (%))
Nezhat et al., 2011	23	0	0	Pain free (100)	NR
Lim et al., 2011	NR	0	0	NR	NR
Brudie et al., 2012	2	2 (2.5)[b]	4	Significant reduction (99)	NR
Ercoli et al., 2012	6	1 (4.5)[c]	0	Significant reduction	NR
Bedaiwy et al., 2013	NR	1 (2.3)[d]	1	NR	NR
Neme et al., 2013	12	0	0	Pain free (100)	4/6 (67)
Collinet et al., 2014	10	6 (3.7)[e]	1	Pain free (88)	11/39 (28)
Siesto et al., 2014	28	2 (4.7%)[f]	0	NR	NR
Pellegrino et al., 2015	22	1 (4%)[g]	0	Significant reduction (75 –100)	4/15 (27)
Abo et al., 2016	24	1 (2.9)[h]	0	Significant reduction	8/9 (89)
Morelli et al., 2016	12	0	0	Significant reduction	1/4 (25)
Total	15 (2 –28)	14 (3.1)	6 (1.3)	–	28/73 (38)

[a] Percentage among women seeking pregnancy.
[b] Ureteral injury, vaginal cuff abscess requiring reoperation.
[c] Small bowel occlusion.
[d] Vaginal cuff abscess.
[e] Two ureteral fistula, 2 bowel injury, 1 ureter bladder anastomotic leak, 1 prolonged urinary catheterization.
[f] Anastomotic leakage, hemoperitoneum requiring reoperation.
[g] Opening of rectal wall during shaving.
[h] Ureteral necrosis and fistula.
NR = not reported; Values are mean (range), or number (%).

and 5.4% versus 35%, respectively (Magrina et al., 2015). In each of the remaining five studies, the rate of hysterectomy in the RAL versus the SL group was 25% versus 21% (Nezhat and Sirota, 2014), 0% versus 0% (Cassini et al., 2014; Dulemba et al., 2013; Nezhat et al., 2015) and not reported (Nezhat et al., 2010), respectively. In one study (Cassini et al., 2014), all patients underwent colorectal resection.

The characteristics of the patients and the perioperative data of the six comparative studies are reported in **Table 4**. In one study (Nezhat and Sirota, 2014), the median BMI in the RAL group was significantly higher than SL group.

Operating time was significantly longer in the RAL group compared with the SL group in five studies (Cassini et al., 2014; Magrina et al., 2015; Nezhat et al., 2010, 2015; Nezhat and Sirota, 2014), and comparable between RAL and SL groups in one study (Dulemba et al., 2013). However, in one study, the longer operating time was explained by the higher number of procedures and more radical operations in the RAL group. In this study, multivariate analysis showed that RAL was actually associated with a 16% reduction in operating time compared with SL (Magrina et al., 2015). In another study (Nezhat and Sirota, 2014), when operating times were correlated to patients' BMI, a longer operating time for RAL compared with SL was observed only for obese patients with a BMI ≥30 kg/m^2, whereas operating time was comparable between the two groups among normal weight and overweight patients.

Hospital stay was significantly longer in the RAL group in one study (Nezhat et al., 2015). In another study, hospital stay was longer in the RAL group at univariate analysis, but comparable between RAL and SL at multivariate analysis (Magrina et al., 2015). Hospital stay was comparable between RAL and SL groups in two studies (Cassini et al., 2014; Nezhat and Sirota, 2014), although in one of these studies (Cassini et al., 2014) the data for the SL group were not reported.

No study has reported a significant difference in blood loss between RAL and SL.

Intra- and post-operative complications and post-operative follow-up of the comparative studies are reported in **Table 5**. The rate of major complications was 1.5% in the RAL group and 0.3% in the SL group and the rate of conversion to laparotomy was 0.3% in the RAL group and 0.5% in the SL group. In four studies, follow-up time was 42 days or less (Dulemba et al., 2013; Magrina et al., 2015; Nezhat et al., 2010; Nezhat and Sirota, 2014), in one study follow up was not reported (Nezhat et al., 2015). In one study, a 6-month follow up evaluation was reported only for the RAL group, with a significant reduction of pain symptoms compared with pre-operative assessment and a pregnancy rate of 2/19 (10%) (Cassini et al., 2014).

Discussion

Available data from non-comparative series of women that were operated using RAL, show that this treatment of endometriosis is feasible and safe. These non-comparative studies reported a low rate of complications and a significant reduction of pain at a mean follow-up of 15 months (Abo et al., 2016; Brudie et al., 2012; Collinet et al., 2014; Ercoli et al., 2012; Morelli et al., 2016; Neme et al., 2013; Nezhat et al., 2011; Siesto et al., 2014). The surgical procedures successfully performed by RAL include radical treatment of the most severe, surgically demanding and painful (Vercellini, 1997) form of the disease, which is deeply infiltrating endometriosis involving the bowel or the urinary tract. Although these results appear encouraging, comparative studies, including women operated using RAL and women operated using SL by the same surgical team, did not show any substantial advantage

Table 4 – Characteristics of retrospective cohort studies comparing robotic-assisted and standard laparoscopic surgery for the treatment of endometriosis. Literature data, 2010–2015.

Author, year	Patients (number)		Age (mean or [b]median (years))		BMI (mean or [b]median)		Previous surgery number (%)		Operating time (minutes) (mean or [b]median (range))		Blood loss (ml)		Hospital stay (days)	
	RAL	SL	RAL	SL	RAL	SL	RAL	SL	RAL	SL	RAL	SL	RAL	SL
Nezhat et al., 2010	40	38	35	33	24	23	18 (45)	15 (39)	191 (135–295)	159 (85–320)[a]	60 (0–350)	65 (0–500)	NR	NR
Dulemba et al., 2013	180	100	33	29	28	27	124 (69)	65 (65)	77	72	29	25	NR	NR
Cassini et al., 2014	19	46	37	NR	21	NR	NR	NR	370[b] (250–720)	180[b] (80–220)[a]	150 (50–350)	320 (100–650)	5 (3–8)	NR
Nezhat and Sirota, 2014	32	86	39[b]	38[b]	27[b]	24[a]	22 (69)	53 (62)	250[b] (176–328)	173[b] (123–237)[a]	100[b] (50–200)	100[b] (50–200)	1	1
Magrina et al., 2015	331	162	40	38	26	26	NR	NR	139 (40–531)	113 (28–347)[a]	92 (10–2500)	82 (10–700)	1.1	0.7[a]
Nezhat et al., 2015	147	273	30[b]	31[b]	23	23	35 (24)	107 (39)	196	135[a]	40	25	>1	1[a]
Total	749	705	36	34	25	25	199 (50)	240 (48)	204 (40–720)	139 (28–347)	79	103	–	–

[a] $P < 0.05$.

Data are mean or [b]median (range) or number (%).

BMI = body mass index; NR = not reported; RAL = robotic-assisted laparoscopy; SL = standard laparoscopy.

of the former over the latter technique. In particular, the only statistically significant differences were in favour of SL, with a reduced operating time in three studies (Cassini et al., 2014; Nezhat et al., 2010, 2015) and a reduced hospital stay in one study (Nezhat et al., 2015). However, comparative studies were all retrospective and they lack an adequate follow-up. Because in these studies the comparison between RAL and SL has been limited to perioperative outcomes, by no means has it been possible to draw any conclusion about the most important outcomes such as long-term relief of pain, pregnancy rates in infertile women and variation in health-related quality of life. Only adequately designed randomized trials comparing RAL and SL for the treatment of endometriosis would disentangle these issues.

Recently, a review and meta-analysis on the robotic treatment of advanced endometriosis has been published, which concluded that RAL required a higher mean operating time than SL, with no significant differences between the two groups in blood loss, complications and hospital stay (Chen et al., 2016). However, the present review was performed because it was found that a few more papers could be included. In fact, among the four studies considered in the review by Chen et al. (2016), one is a retrospective study that has also been included (Nezhat et al., 2015), and the remaining studies are three abstracts, all from the same principal investigator (Chu et al., 2011; Sirota and Nezhat, 2013, 2014), of whom a full paper has been included, which is most likely based on the same series of women included in the three abstracts (Nezhat and Sirota, 2014). We believe that the strength of the present review is the rigorous methodology adopted. A thorough literature review was performed using an accepted modality for article search. To avoid major bias in data gathering, these were extracted from the reports by two independent observers who were not blinded. Rejected studies have been described and the reason for their exclusion and a formal evaluation of the quality of the selected studies has been performed. The limit of the present review is that the overall quality of the studies included is low. Despite this limitation, the data included in this analysis constitute the only available evidence on which to base clinical decision-making.

With regard to the treatment of benign gynaecological conditions in general, a recent American Association of Gynecologic Laparoscopists position statement (AAGL, 2013) as well as a Cochrane review (Liu et al., 2012) suggest that robotic surgery offers no patient benefits compared with SL. Along the same line, the American College of Obstetrician and Gynecologists, as part of the Choosing Wisely® campaign, has issued the general evidence-based recommendation to 'avoid using robotic-assisted laparoscopic surgery for benign gynecologic disease when it is feasible to use a conventional laparoscopic or vaginal approach' (ACOG, 2016). However, such statements have been mainly based on data related to benign gynaecologic conditions other than endometriosis, without a specific focus on the endometriotic disease.

In a recent commentary, the main argument in favour of RAL versus SL was that the use of the former technique lowers the proportion of patients having open surgery for endometrial cancer, with conversion rates that are probably halved compared with SL (Ind, 2014). However, it has to be underscored that gynaecologists that deal with endometriosis, compared with gynaecologic oncologists, are used to being trained in standard laparoscopic surgery from the very beginning of their practice, by treating less advanced cases such as ovarian endometriotic cysts and infertility. This is confirmed by the extremely low rate of conversions to laparotomy documented in the present review. For this reason, the development of a sophisticated

Table 5 – Operative and postoperative findings of retrospective cohort studies comparing robotic-assisted and standard laparoscopic surgery for the treatment of endometriosis. Literature data, 2010–2015.

Author, year	Patients (number)		Follow up (days) (mean or range)		Major complications (number (%))		Conversion to laparotomy	
	RAL	SL	RAL	SL	RAL	SL	RAL	SL
Nezhat et al., 2010	40	38	28–42	28 – 42	0	0	0	0
Dulemba et al., 2013	180	100	14	14	1 (1)[a]	0	0	0
Cassini et al., 2014	19	46	180	NR	2 (11)[b]	NR	0	1 (2)
Nezhat and Sirota, 2014	32	86	30	30	2 (6)[c]	1 (1)[d]	0	0
Magrina et al., 2015	331	162	42	42	6 (2)[e]	1 (1)[e]	2 (1)	1 (1)
Nezhat et al., 2015	147	273	NR	NR	0	0	NR	NR
Total	749	705	60	31	11 (1.5)	2 (0.3)	2 (0.3)	2 (0.5)

[a] Intraoperative inadvertent cystotomy.
[b] Two rectovaginal fistulas.
[c] Bowel perforation, gastrointestinal fistula.
[d] Gastrointestinal fistula.
[e] One ureteral peritoneal leak, two pelvic abscesses, two partial small bowel obstructions, two intraoperative (one inadvertent sigmoid enterotomy and one inadvertent cystotomy).
Data are number (%).
NR = not reported; RAL = robotic-assisted laparoscopy; SL = standard laparoscopy.

and expensive technique with the aim of reducing laparotomies and increasing minimally invasive procedures seems unfounded.

Nevertheless, even among experienced laparoscopic surgeons that deal with endometriosis, the use of RAL has been advocated, especially in the subgroup of women with severe endometriosis requiring difficult surgical procedures. In these women, the benefit of RAL may be in reducing the number of procedures performed at laparotomy. Such improvement would be the logical consequence of the high degree of movements allowed by the robotic instruments, making the robotic procedure more intuitive and more similar to the open abdomen technique compared with SL. However, such argument does not seem to be substantiated by the findings of the present review, because the rate of severe endometriosis cases that are managed by SL in referral centres for the treatment of endometriosis is very high *already*, approaching 100%, with rates of conversion to laparotomy that are not different between RAL and SL. Of relevance here, is that the clinical characteristics of advanced endometriosis involving the bowel or the urinary tract, namely the availability of an accurate preoperative diagnosis by means of transvaginal ultrasound and magnetic resonance imaging and a limited prevalence in the overall female population, allows the optimizing of surgical treatment of the disease in referral centres by high-volume surgeons. In this scenario, standard laparoscopic surgery offers safe and cost-effective outcomes.

Furthermore, when evaluating the perioperative performances of RAL and SL among women requiring difficult surgical procedures, there seems to be a strong argument against robotic surgery in cases when the operating field is not limited to the pelvis. In fact, in the opinion of surgeons that master both SL and RAL, in these cases 'because the robotic camera is not interchangeable between ports and the arms are not so easily manoeuvrable in extrapelvic sites, use of the robotic platform would have been time consuming and intricate' (Nezhat et al., 2015). The surgical procedures in which at least one step of the operation must be performed outside of the pelvis, are typically rectosigmoid resections, which require the mobilization of the descending colon from the splenic flexure. Accordingly, most surgeons advocate in these cases a 'hybrid' technique, meaning that during RAL operations the robot is temporarily undocked and one or more surgical steps are performed via SL. However, a study that included only women undergoing colorectal resection for endometriosis has reported a median operating time twice as long for the RAL-hybrid technique (370 min) than for SL (180 min) (Cassini et al., 2014). According to available clinical data, therefore, the use of RAL instead of SL does not seem justified in women with advanced disease and requiring difficult surgical operations, especially in cases when lesions are located also outside the pelvis or colorectal resection is required.

Another specific subgroup of women who may benefit from RAL instead of SL may be that of women suffering from pelvic pain suggestive of endometriosis. In these women, the improved three-dimensional visualization associated with robotic technology could increase the capacity of visually diagnosing peritoneal endometriosis. As a demonstration, a significantly higher rate of biopsies confirming endometriosis was found in the RAL group than in the SL group (80% versus 57%, respectively) (Dulemba et al., 2013). However, we believe that this observation is of limited clinical importance. Firstly, these findings have not been confirmed by independent investigators. Moreover, 3D visualization is available for standard laparoscopy too, which may narrow the gap of visualization quality between the two techniques. Finally, there is no proof that detecting endometriosis in a higher number of peritoneal biopsies translates into practical benefits for the patient.

Another subgroup of women with endometriosis who may benefit from RAL rather than SL is represented by obese women, as proposed by Nezhat and Sirota (2014). However, such a proposal does not seem to be supported by the data presented by these same authors, since they reported higher operating time for RAL compared with SL specifically and only among obese women (Nezhat and Sirota, 2014). On the contrary, Cassini et al. (2014) strongly recommend a robotic hybrid procedure especially in obese patients or those with abundant visceral fat in order to avoid multiple changing in table position. Therefore, according to available evidence, there are no subgroups of women with endometriosis for whom RAL has proven advantageous over SL.

On the basis of the limited data available we conclude that, similarly to what has been reported for benign gynaecologic diseases in general, the indications for robotic surgery for the treatment of

endometriosis still need to be defined. Indeed, the hypothetical role of robotic assistance in reducing laparotomic in favour of minimally invasive surgery, seems to apply only to those surgeons that are not skilled and experienced enough to using standard laparoscopy for difficult procedures. From this standpoint, the implementation of RAL, due to the lack of evidence of any clinical advantage over SL, would be mostly a benefit for the surgeon rather than for the patient. A possible exception, although evidence is limited due to the rarity of the condition and although data were not presented in this review, is represented by large diaphragmatic endometriotic lesions. In the removal of these lesions, the superiority of robotic assistance has been advocated by skilled laparoscopic surgeons, because they found that robotic suture of the diaphragm becomes particularly easier (Roman et al., 2016). Further studies are necessary to validate this recent preliminary observation.

Another argument in favour of the implementation of robotic surgery is the supposedly shorter learning curve associated with this technique compared with SL. However, no studies have demonstrated this hypothesis in a clinical setting for any specific surgical procedure (AAGL, 2013). Previous studies that have investigated this issue suggest that robotic assistance for laparoscopy may reduce or eliminate the early learning curve for novices but does not provide advantages for experienced laparoscopic surgeons (Chandra et al., 2010; Yohannes et al., 2002). A study evaluating specifically the impact of 3D vision in completing a suturing task among surgeons with different levels of expertise in laparoscopic surgery concluded that the previous observation, that tasks were completed faster with a robot system (Wagner et al., 2012), may be true for novices only (Park et al., 2016). Again, it has to be noted that, because laparoscopic surgery is recognized as the technique of choice for the treatment of endometriosis, the laparoscopic training of young surgeons approaching the disease begins very soon in their professional life. Consequently, the additional costs associated with RAL seems currently unjustified by a possible, undefined shortening of the learning curve for the minimally invasive treatment of endometriosis.

In the first report on the comparison between RAL and SL for endometriosis, published in 2010 (Nezhat et al., 2010), the authors recognized the limitations of RAL and advocated a future technological development in which 'smaller, cheaper and easier to use robots are going to make this alternative form of surgery faster and more cost-effective'. Unfortunately, after more than 6 years, such expectations of technological improvement have not been realized. This may partly be explained by the fact that there is only one robotic system on the market, the da Vinci robot produced by Intuitive Surgical, Inc (Sunnyvale, California, USA). When the only past competitor Computer Motion, which developed the ZEUS robotic system, merged with Intuitive Surgical in 2003, a monopoly of Intuitive Surgical was created for the market of robotic surgery. In this monopoly condition, the financial investments undertaken by Intuitive Surgical to developing more effective and more affordable robotic systems might remain substantially lower than they would be in presence of the competitive pressure of another company.

The da Vinci robotic system was approved by the United States Food and Drug Administration with limited clinical evidence of safety or effectiveness (Paul et al., 2013). In the absence of proof that RAL is superior to SL, many investigators simply skip this issue and try to move on to the question of how we should better adopt this new technology (Steege and Einarsson, 2014). Of relevance here, in 2014 Intuitive Surgical, Inc. has been the second leading payer to US obstetricians and gynaecologists and the leading payer to US gynaecologic oncologists, in terms of money transferred for non-research purposes, such as participation at conferences and courses, travel and lodge, meals, speaker fees and consultancies (Shalowitz et al., 2016; Tierney et al., 2016). Therefore, when evaluating the studies reporting the outcomes of robotic surgery, sponsorship of industry and possible conflicts of interests of authors should be taken into account. In fact, it is known that studies sponsored by industry almost always report more favourable outcomes for the experimental technique compared with independent studies (Flacco et al., 2015; Lundh et al., 2012).

The diffusion of the da Vinci robot, rather than being based on evidence derived from independent, randomized trials, seems to be mainly the result of well-designed marketing campaigns. Robotic surgery, in fact, is presented on the market as the ultimate technology and it has become a symbol of providing advanced care. Consequently, women may seek for robotic surgery and the number of da Vinci robots and robotic surgeons may increase to provide this cutting-edge, ultimate surgical technology to them. However, marketing the robot to patients as something that permits better surgery than regular laparoscopy, in the absence of robust evidence showing definite clinical advantages of RAL over SL, seems unethical. Moreover, the combination of these aggressive marketing strategies with a market monopoly, is potentially dangerous. In fact, if a self-propagating cycle takes place and the presence of the da Vinci robot expands from a limited number of teaching hospitals to virtually all hospitals, the costs for healthcare providers would become unacceptably high. Accordingly, it has been calculated that, if robotic surgery were to replace conventional surgery for all surgical procedures, the additional cost would be more than $2.5 billion every year (Barbash and Glied, 2010).

Because an uncontrolled growth of robotic surgery would not be sustainable in the current medico-economic environment, it is of paramount importance that its implementation take place in research hospitals in order to evaluate the possible benefits of this technique for the patients. On the contrary, in the absence of robust evidence showing definite clinical advantages of RAL, limited healthcare resources should be employed in implementing surgical training in SL, in order to avoid the development of an irreversible dependence from the da Vinci robot. The ultimate goal of healthcare policies should be that of directing women requiring surgical treatment for advanced endometriosis towards high volume providers who are able to provide safe and cost-effective surgical care.

In conclusion, RAL for the treatment of endometriosis did not show any perioperative advantage compared with SL, whereas it was associated with a longer operating time in some studies. The absence of advantages of RAL over SL was confirmed also among subgroups of women who were supposedly more likely to benefit from the former technique such as women with severe endometriosis, women with pelvic pain suggestive of endometriosis and obese women. Since the quality of available studies comparing RAL and SL for the treatment of endometriosis is low and, moreover, data regarding long-term pain relief and pregnancy rates are lacking, adequately designed randomized trials are needed to investigate the role of RAL for the treatment of endometriosis. Due to the higher costs, RAL treatment of endometriosis should be performed only within controlled studies.

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