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ORIGINAL ARTICLE

Robotic laparoendoscopic single-site benign gynecologic surgery: a single-center experience

J. Jayakumaran[1] · K. Wiercinski[2] · C. Buffington[2] · A. Caceres[1,2]

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Abstract The da Vinci Xi surgical system was released with several upgrades and modifications compared to the previous robotic generations to facilitate minimal invasive surgery. Herein, we present our preliminary experience of robotic laparoendoscopic single-site gynecologic surgery performed for benign indications with the da Vinci Xi robotic system in a single center. Thirty-five female patients underwent robotic single-site surgery between June 2016 and January 2017. The median console time for hysterectomy with or without salpingo-oophorectomy was 41 min. The median intracorporeal vaginal cuff closure time was 18 min. Two cases (5.7%) were converted to robotic-assisted multiport surgery. There was one major intraoperative complication (2.9%). None of the patient required blood transfusion. When comparing our first 12 cases to subsequent 12 cases of R-LESS hysterectomy, there was a statistically significant decrease in surgical times and estimated blood loss. On logistic regression analysis, no association was detected between BMI and port entry time (OR 0.93, 95% CI 0.83–1.04, $p = 0.23$), console time (OR 0.98, 95% CI 0.94–1.02, $p = 0.37$), cuff closure time (OR 0.9, 95% CI 0.76–1.09, $p = 0.33$), operative time (OR 1, 95% CI 0.98–1.01, $p = 0.97$), and estimated blood loss (OR 0.98, 95% CI 0.96–1.01, $p = 0.33$). Our preliminary experience with robotic laparoendoscopic single-site surgery using the da Vinci Xi system has demonstrated feasibility and safety in select patients. Further studies with greater number of patients in multiple settings will help us to fully elucidate the role of da Vinci Xi surgical system in single-site gynecologic surgery.

Keywords Robotic laparoendoscopic single-site surgery · Single-port surgery · da Vinci Xi surgical system · Robotic surgery

Introduction

Minimally invasive surgery (MIS) has been used extensively for the management of benign and malignant gynecologic conditions. As each working port carries with it an inherent risk of bleeding, infection, concordant organ damage, hernia formation, and decreased cosmesis, the natural goal in the field of MIS is to reduce the number of ports to perform the procedure [1]. Technologic advances in endoscopic instrumentation and optics have allowed the development of laparoendoscopic single-site surgery (LESS) with the goal to improve cosmesis and to reduce patient invasiveness [2–4]. However, transition from multiport surgery to LESS has been challenging owing to instrument clashing, unstable camera platform, reverse handedness, and loss of triangulation [5]. The application of robotic platform to LESS (R-LESS) has addressed some of these limitations [6–8]. In the literature, a comparison between R-LESS and LESS hysterectomy has been performed that reported longer operating times, lesser blood loss, decreased length of stay, and favorable learning curve for R-LESS [9, 10].

Most of the experience in single-site robotic surgery has been described for the Si Platform [6–8, 11]. The latest, fourth-generation robot, da Vinci Xi surgical system was released with several upgrades and modifications compared to the previous robotic generations including overhead

✉ J. Jayakumaran
drjphari@gmail.com

[1] Department of Obstetrics and Gynecology, University of Central Florida College of Medicine, 70 West Gore Street, Orlando, FL 34743, USA

[2] Florida Hospital Celebration Health, Celebration, FL, USA

docking, narrower arms, and greater range of motion without external collision, providing improved anatomic access. Herein, we present our preliminary experience of robotic laparoendoscopic single-site gynecologic surgery performed for benign indications with the da Vinci Xi surgical system.

Materials and methods

This is a retrospective cohort study analyzing R-LESS benign gynecologic procedures performed between June 2016 and January 2017 in a single center. Procedures included in the study were total hysterectomy with or without adnexectomy, myomectomy, paraovarian cystectomy, excision of endometriotic lesions, and trachelectomy. A single surgeon with advanced skills in the conventional laparoscopic and robotic surgery performed all procedures. This study met Florida Hospital Institutional Review Board approval. Inclusion criteria were women with a uterus size of 14 weeks or less, presumed benign condition based on clinical evaluation and/or preoperative imaging, and were otherwise reasonable medical candidates for laparoscopic surgery. There were no restrictions by body mass index (BMI). The da Vinci single-site instruments and accessories are approved by the United States Food and Drug Administration for cholecystectomy, benign hysterectomy, and salpingo-oophorectomy. Other off-label usage of these instruments was explained to patients and informed consent obtained.

Patient demographics and perioperative outcomes were retrieved from the electronic medical records. Collected demographic data included: age, BMI (weight in kilograms divided by the square of height in meters), preoperative diagnosis, and procedure type. Intraoperatively, performance time for each procedural step was recorded. Port entry time was defined as time from umbilical incision to single-port placement. Robotic docking time consisted of the time to move the robot toward the operating table, fastening the robotic arms to the inserted trocars, and placement of all robotic instruments. Surgeon console time was defined as the total time that the surgeon was at console until completion of procedure. Vaginal cuff closure time was specified as the time between insertion of the robotic single-site needle holder into the abdomen and its removal at the end of closure. Total operative time was defined as the interval between skin incision start to skin closure. Surgical data collected included estimated blood loss (EBL), intraoperative/postoperative complications,

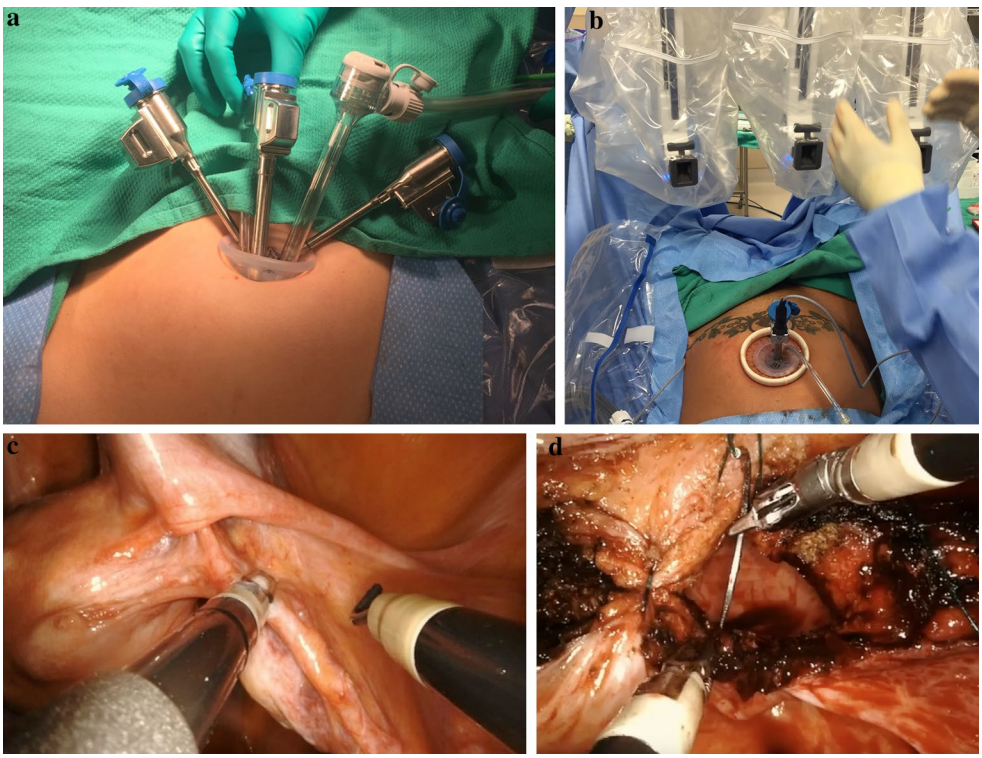


Fig. 1 **a** da Vinci Xi trocars placed through Gelport (Intuitive Surgical, Sunnyvale, CA, USA) for single-site robotic-assisted laparoscopic hysterectomy. **b** da Vinci Xi robot pelvic docking for robotic laparoendoscopic single-site procedure. **c** Single-site instruments—5-mm bipolar Maryland grasper and monopolar hook used in hysterectomy. **d** Single-site 5-mm wristed needle driver used for vaginal cuff closure in hysterectomy

Table 1 Patient characteristics

Characteristics	
Age [years (median, range)]	45 (17–70)
BMI [kg/m^2 (median, range)]	27 (18.4–41.9)
Indications for surgery (*n*, %)	
Pelvic pain	16 (45.7%)
Fibroids	11 (31.4%)
Adenomyosis	2 (5.7%)
Uterine prolapse	2 (5.7%)
Bleeding	2 (5.7%)
Cervical dysplasia	1 (2.9%)
Paratubal/mullerian cyst	1 (2.9%)
Procedure type (*n*, %)	
TLH with and without BSO	24 (68.6%)
Excision of endometriosis	5 (14.3%)
Myomectomy	3 (8.5%)
Trachelectomy	2 (5.7%)
Paraovarian cystectomy	1 (2.9%)

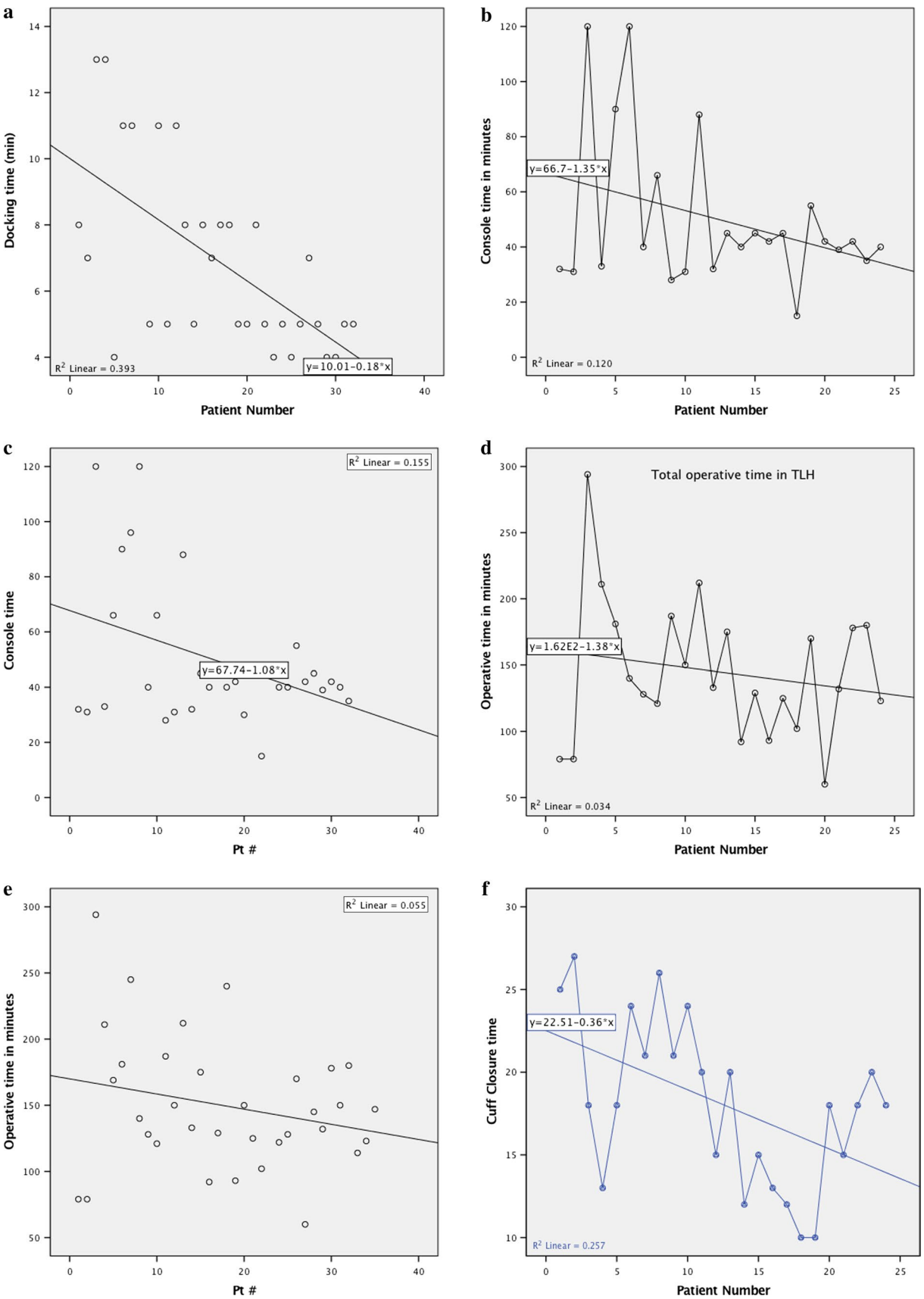
conversions to multiport robotic surgery/standard laparoscopy/laparotomy, blood transfusions, uterine weight (in hysterectomy cases), pain scores, and length of hospital stay (LOS). Estimated blood loss was evaluated using the difference between washed and suctioned solution. Postoperative complications that occurred in the first 6 weeks after surgery were recorded according to the Clavien–Dindo classification [12]. Postoperative pain evaluation was performed for all patients, using the visual analog scale in the range 0 = no pain to 10 = agonizing pain. Patients were asked to rate their pain intensity at regular intervals, T0 (at PACU admission), T1 (PACU discharge), T2 (after 6 h of surgery), T3 (after 12 h of surgery), and T4 (at hospital discharge). The standard analgesic therapy with acetaminophen was given intraoperatively (1000 mg intravenous) in all patients, unless contraindicated. At the end of surgery, bupivacaine 0.5% local infiltration was performed at the single-site port access. Postoperatively intravenous ketorolac 30 mg single dose and Tramadol 50 mg per-oral PRN were also utilized for pain control. Hospital length of stay was measured from admission to discharge. All patients received venous thromboembolism prophylaxis. All patients were seen and examined in the office at 2 and 6 week postsurgery.

In addition, we also classified the patients that underwent R-LESS hysterectomy into two groups according to the chronological order based on procedure date. Group I consisted of the first 12 patients in our series, and Group II consisted of the second 12 patients. We compared the operative times and estimated blood loss between both groups.

All of the interventions were performed using a da Vinci Xi surgical system. A single 2.5-cm sub-umbilical incision was made via an open Hasson approach. A multichannel single-port system, GelPort (Intuitive Surgical, Sunnyvale, CA, USA), was used in all cases. The port is a five-lumen port providing access for two single-site instruments and 8.5-mm endoscope, a 5–10-mm accessory port, and insufflation adapter (Fig. 1a, b). Port was inserted through the fascial opening created by the surgeon utilizing a Kelly clamp to stabilize the port entry. For deep umbilical stalks or obese patients (BMI > 30), the Wound Retractor (Applied Medical, Rancho Santa Margarita, CA, USA) was used. It has an inner flexible retraction ring which can be inserted into the small incision and accommodate the feasibility of insertion of the GelPort. The outer rigid, extra-peritoneal retraction

Table 2 Operative outcomes of patients that underwent R-LESS gynecologic surgery

Parameter (median, range)	TLH ± BSO (*n* = 24)	Excision of endometriosis (*n* = 5)	Myomectomy (*n* = 3)	Trachelectomy (*n* = 2)	Paraovarian cystectomy (*n* = 1)	All patients (*n* = 35)
Duration in minutes						
Port entry time	12 (5–47)	21 (16–25)	11 (9–14)	15	15	14 (5–47)
Docking time	7 (4–13)	8 (4–11)	4.5 (4–5)	5	5	5 (4–13)
Console time	41 (25–120)	66 (40–96)	40 (40–45)	30	45	40 (15–120)
Cuff closure time	18 (10–27)	NA				18 (10–27)
Total operating time	132 (60–294)	240 (169–245)	125 (114–150)	148.5 (147–150)	145	142 (60–294)
Estimated blood loss in ml	75 (20–300)	50 (25–150)	150	50	75	75(20–300)
Uterine weight (gm)	176 (46–532)					
Conversions (n, %)	1	1	0	0	0	2 (5.7%)
Transfusion needed	0	0	0	0	0	0
Hospital stay in hours	23 (23–120)	23 (23–168)	23	23	23	23 (23–168)
Major complication	1	0	0	0	0	1 (2.9%)


a
Docking time (min)
Patient Number
y=10.01-0.18*x
R² Linear = 0.393
b
Console time in minutes
Patient Number
y=66.7-1.35*x
R² Linear = 0.120
c
Console time
Pt #
y=67.74-1.08*x
R² Linear = 0.155
d
Total operative time in TLH
Operative time in minutes
Patient Number
y=1.62E2-1.38*x
R² Linear = 0.034
e
Operative time in minutes
Pt #
R² Linear = 0.055
f
Cuff Closure time
Patient Number
y=22.51-0.36*x
R² Linear = 0.257

◂**Fig. 2** **a** Trends in docking times with experience. **b** Trends in hysterectomy console times with experience. **c** Trends in total console times with experience. **d** Trends in hysterectomy operative times with experience. **e** Trends in total operative times with experience. **f** Trends in hysterectomy vaginal cuff closure times with experience

ring provides a large surface area for trocar placement. The robotic instruments used were the monopolar hook in cannula number 2 and the bipolar Maryland grasper or fenestrated bipolar in the cannula number 1 position (Fig. 1c). The da Vinci system software automatically detects and reassociates the user's hands with the instrument tips after docking, so that the left hand of the surgeon will control the right arm (arm 1) of the robot, and the right hand will control the left arm (arm 2). The da Vinci Xi platform provides for a wristed needle driver which was used for vaginal cuff closure (Fig. 1d). The 5-mm Single-Site Wristed Needle Driver™ was developed in part to facilitate suturing, as it can move the instrument tip up to 45° in all directions for precise needle positioning (Intuitive Surgical, Sunnyvale, CA).

After completion of the surgery, the fascial defect was closed with a delayed absorbable suture in a running or interrupted fashion. The skin was closed with an absorbable suture in a subcuticular or interrupted fashion.

Statistical analysis

All continuous data with normal distributions were expressed as mean ± SD. The median and range were utilized for skewed data. Categorical data were reported as an absolute number or percentage. Frequency distributions were compared using Chi-square test, and mean or median values were compared using Student's *t* and Mann–Whitney *U* tests. The association between BMI and the continuous outcomes of procedural times and estimated blood loss was studied using binomial logistic regression model. Odds ratio was reported along with a 95% confidence interval and the *p* value. All calculated *p* values were two-sided, and $p < 0.05$ was considered statistically significant. Data were analyzed using SPSS statistics, version 24.0 (IBM Corp., Armonk, NY, USA).

Results

A series of 35 female patients underwent R-LESS at our center during the study period. Table 1 lists the demographic patient characteristics. The median patient age was 45 years and the median BMI was 27 kg/m^2. Sixty-eight percent of surgical procedures were total laparoscopic hysterectomies with or without salpingo-oophorectomy (TLH with or without BSO). For operative parameters (Table 2), the median docking time was 5 min and median port placement time was 14 min. For patients that underwent TLH with or without BSO, the median console time was 41 min and the median intracorporeal vaginal cuff closure time was 18 min. The mean uterine weight was 207.54 gm. There appeared to be a linear relationship between docking time, console time, operating time, and cuff closure time with the number of cases performed (Fig. 2a–f). Median blood loss was 75 ml and the median hospital stay was 23 h. All patients experienced low postoperative pain. The mean pain score at T0 was 2.4, at T1 was 1.8, at T2 was 2.5, T3 was 3.2, and at T4 was 2.6 (Fig. 3).

Two cases (5.7%) were converted to robotic-assisted multiport surgery due to dense endometriotic adhesions that made the single-port access difficult. One of these multiport conversions occurred in a patient that underwent TLH. She had stage 4 endometriosis with dense adhesions to bladder and bowel. During adhesiolysis, incidental cystotomy occurred and the same was repaired. No other major perioperative complications were reported in our series. None of the patients required blood transfusion. Ninety-four percent of patients were discharged by 23 h. Another patient, a 28-year-old woman with endometriosis and partial bowel obstruction underwent excision of endometriosis with bowel resection and had a hospital stay of 1 week and the patient that underwent cystotomy repair stayed for 3 days due to pain control.

When comparing our first 12 cases (Group 1) to subsequent 12 cases (Group 2) of R-LESS hysterectomy (Table 3), a statistically significant decrease in surgical times and estimated blood loss was noted, particularly for cuff closure (21 vs 15 min; $p = 0.001$), while age and BMI did not differ between groups. Docking time and console time steadily decreased with experience and showed a 68% reduction in Group 2 compared to Group 1 (8.8 vs 6; $p = 0.01$ and 59.3 vs 40.4: $p = 0.09$). On logistic regression analysis, no association was detected between BMI and port entry time (OR 0.93; 95% CI 0.83–1.04, $p = 0.23$), console time (OR 0.98, 95% CI 0.94–1.02, $p = 0.37$), cuff closure time (OR 0.9, 95% CI 0.76–1.09, $p = 0.33$), operative time (OR 1, 95% CI 0.98–1.01, $p = 0.97$), and estimated blood loss (OR 0.98, 95% CI 0.96–1.01, $p = 0.33$).

Discussion

In this study, we described our cumulative experience with R-LESS gynecologic surgery performed using da Vinci Xi surgical system at a single center. The da Vinci Xi surgical system was released with several upgrades and modifications compared to the previous Si version. First, the robotic arms are smaller and thinner with newly designed FLEX joints

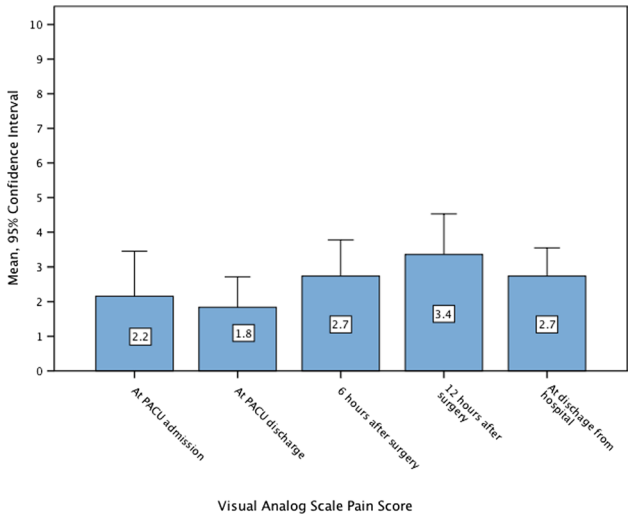


Fig. 3 Postoperative pain scores

that allow closer port spacing, making da Vinci Xi system more suitable for single-site surgery. Next, the instrument shafts are longer than before for greater operative reach. In addition, the torpedo-shaped robotic arms mounted on a rotating beam results in a greater range of motion without external collision. Furthermore, the changeability of camera position offers a more versatile view of the surgical field. These qualities in combination allow access to a greater surgical field.

The most pronounced difference in the Xi is in the docking phase. Expertise is quickly gained for robotic setup and docking. On comparing the first 18 patients in our series to the next 17 patients, we found a 60% reduction in docking times. This is because the docking is simpler, user-friendly, guided by a port placement menu and a laser. The laser-targeting system helps to position the arm beam in the optimal location and allows to automatically arrange the robotic arms in relation with the targeted anatomy. All these facilitated faster system docking.

Our median console time for hysterectomy was relatively short in comparison with other studies on R-LESS hysterectomies performed with prior da Vinci model (range 79–115 min) [10, 13–16]. We performed intracorporeal vaginal cuff closure in all cases. Ours is one of the few studies that have reported intracorporeal cuff suturing using the single-site platform. Our median cuff closure time was 18 min, which was less than the cuff closure times reported in the literature (27–32 min) [14, 17, 18]. We attribute this improved cuff closure time to the wristed needle driver. While performing hysterectomy, the distance from the tip of the cannulas to the vaginal cuff increased after the uterus was removed. This caused the semi-rigid instrument to bend, making it difficult for the surgeon to pass the needle through the vagina. As suggested by Akdemir et al. [18], we pushed the port down on the abdomen to shorten the distance, thus providing support for the cannula. This facilitated vaginal cuff suturing with minimal bending of semi-rigid instruments. We also used a long guide cannula (30 cm) instead, which made the procedure easier and shortened the operation time. In the literature, R-LESS hysterectomy has been reported to take a mean time of 98–170 min [10, 13–17]. Although all cuff closures were performed intracorporeally in our series, our operative times compare favorably to that of the aforementioned studies performed with prior da Vinci Si model. We expect our operating times to decrease further as the team gains further experience and becomes familiar with the single-site surgical system. Iavazzo et al. [19] reviewed single-port robotic technique and reported a 6.25% conversion rate to multiport robotic surgery which is in line with our data. We believe that this conversion rate will further decrease with increasing experience and technologic advancements.

The robotic single-site approach in our series allowed for excellent postoperative pain control. Our mean pain scores measured at different intervals after R-LESS did not exceed 3 in the visual analog pain scale. The single-site platform was fixed completely to the umbilicus, and therefore, the R-LESS instrument functioned without excessive movement. The minor abdominal wall trauma in R-LESS may justify the better control of pain after surgery as previously highlighted by Paek and colleagues [10]. Most importantly, the scar of R-LESS shrunk was hidden inside the umbilicus at 6 weeks after surgery resulting in improved cosmesis.

Table 3 Comparison between first half (Group I) and second half (Group II) of patients that underwent R-LESS hysterectomy

Parameters	Total patients ($n = 24$)	Group I ($n = 12$)	Group II ($n = 12$)	p value
Age (mean ± SD)	47.5 ± 9.4	46.0 ± 5.7	49.0 ± 12.1	0.44
BMI (mean ± SD)	28.7 ± 6.3	27.9 ± 6.4	29.6 ± 6.4	0.52
Port entry time in minutes	17.2 ± 11.5	22.0 ± 14.7	12.3 ± 3.2	0.03
Docking time in minutes	7.4 ± 2.8	8.8 ± 3.1	6.0 ± 1.6	0.01
Console time in minutes	49.8 ± 27.5	59.3 ± 36.0	40.4 ± 9.3	0.09
Cuff closure time in minutes	18.0 ± 5.0	21.0 ± 4.4	15.0 ± 3.7	0.001
Total operating time in minutes	144 ± 52.6	159.6 ± 61.3	129.9 ± 39.3	0.17
Estimated blood loss in ml	87.0 ± 55.5	112.0 ± 65.5	62.0 ± 27.8	0.02

Our study illustrates a few important points. First, operating room efficiency is markedly augmented by increase in surgeon's experience and team familiarity with surgical performance using the single-site platform. On analyzing our data, we found that there was a significant improvement in operative times with increased experience. Cuff closure demonstrated the most marked reduction in time over the course of the study, with a 71.4% reduction in time by the completion. Scheib and Fader [15] showed a similar decreased operative time with experience. Their 134-min total operative time for hysterectomy is comparable with our experience. Meritans et al. [16] also demonstrated that experience impacted operative times of all portions of the procedure and their operative times decreased with experience despite increased surgical complexity. Furthermore, according to our data, large BMI seemed not to have a negative impact on the surgical performance, suggesting that obesity does not preclude the completion of R-LESS hysterectomy. We reported BMI $\geq$ 25 in seven cases and BMI $\geq$ 30 in nine patients. Our results were in line with the findings reported by Bogliolo et al. [13] who stated that R-LESS should also be used for obese patients to achieve the goal of very minimally invasive surgery. At the same time, Svoboda et al. [20] reported no difference in operative time, with less conversion to open in obese patients that underwent robotic single-site cholecystectomy (RSSC) in comparison with nonobese women, stating that patients should not be excluded from opting RSSC as a surgical option based on their high BMI.

The strength of our study is that all surgical procedures were performed by a single high-volume surgeon dedicated to robotic surgery in a single center, which eliminates potential variability in results owing to multiple operators. Furthermore, to the best of our knowledge, ours is the first case series to report on the perioperative outcomes of single-site benign gynecologic surgery performed using da Vinci Xi surgical system. The limitations include retrospective design and the relatively small number of treated patients. Finally, we also did not perform cost assessment as part of this study as larger numbers of patients are required for providing any valuable information regarding cost.

Conclusion

With the da Vinci Xi surgical system, docking was more simple and instrument clashing was minimal. Console time was short and our surgical procedural times decreased with experience. Moreover, our perioperative outcomes were similar to prior experiences with da Vinci Si model. Our preliminary experience has demonstrated that in experienced hands, R-LESS with the da Vinci Xi system is a feasible and safe surgical approach for performance of hysterectomy and adnexal surgery, including in select obese patients. Further studies with greater number of patients in multiple settings will help us to fully elucidate the role of da Vinci Xi surgical system in single-site gynecologic surgery.

Compliance with ethical standards

Conflict of interest Jayapriya Jayakumaran, Wiercinski Karen, Cynthia Buffington, and Aileen Caceres declare that they have no conflict of interest".

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This is a retrospective study. For this type of study, formal consent is not required.

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