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EDUCATION AND TRAINING

Learning curve analysis of the first 100 robotic-assisted laparoscopic hysterectomies performed by a single surgeon[☆]

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ABSTRACT

Objective: To review the first 100 cases of robotic-assisted hysterectomy performed by an individual surgeon. *Methods:* A retrospective cohort study of the first 100 consecutive patients who underwent robotic-assisted hysterectomy by a newly trained minimally invasive gynecologic surgeon was conducted. Demographic factors and short-term surgical outcome variables were abstracted from medical records. We examined univariate associations and performed multivariable modeling with linear regression, and modeled the learning curve for total operative time using power-law function. *Results:* Mean age was 46 years; mean body mass index was 27.8 kg/m^2. Median operative time was 120 minutes; median estimated blood loss was 100 mL. On multivariable analysis, case number (β –0.296; $P < 0.005$) and uterine weight (β 0.330; $P < 0.005$) independently predicted operative time, while uterine weight (β 0.387; $P < 0.005$) independently predicted estimated blood loss. The point at which the slope of the case number–operative time curve crosses –1.0 is at case 28 when uncontrolled and at case 24 when controlled for other factors. *Conclusion:* There was a significantly decreased operative time for robotic-assisted hysterectomies performed later in the surgeon's learning curve. Surgical proficiency, as measured by operative time, seemed to be attained after 20–30 cases.

1. Introduction

Hysterectomy is the most commonly performed gynecologic surgery, with more than 500 000 cases each year in the USA [1]. Despite extensive literature on the benefits of minimally invasive surgery—including lower perioperative morbidity, improved quality of life, shorter hospital stay, and more rapid return to activity—abdominal hysterectomy remains the most common approach [2,3]. Commonly cited explanations for this dichotomy include lack of adequate training in residency programs, lack of available training opportunities outside of fellowships, lack of mentor surgeons, and hesitancy among established surgeons to attempt a new system with a perceived long learning curve for reaching surgical proficiency [4–6]. Nevertheless, there is a clear trend in all surgical fields, driven by patient demand and outcomes reported in the literature, toward minimally invasive procedures.

The literature on surgeon learning curves for robotic procedures is just beginning to emerge and remains insufficient. The general surgery and urology literature has reported learning curves to be between 150 and 200 cases [6–9]. Gynecologic oncology data indicate a much faster learning curve of approximately 20–25 cases for robotic-assisted endometrial cancer-staging procedures [10,11]. The benign gynecology numbers lie somewhere between the experience of the urologists and the gynecologic oncologists. Payne and Dauterive [12] reported attaining proficiency for robotic-assisted hysterectomy within the first 75 cases. Lenihan et al. [5] found that it took approximately 50 robotic cases to develop consistent operative times and predictable outcomes that were consistent with those from other initial series reported by gynecologic robotic surgeons [13–16]. Most of these studies included multiple surgeons and it remains unclear how many surgical cases are required for a single surgeon to reach proficiency and maintain efficiency.

The aim of the present study was to review the first 100 cases of robotic-assisted hysterectomy performed by an individual surgeon.

2. Materials and methods

A retrospective clinical chart review was conducted of the first 100 consecutive cases of robotic-assisted total laparoscopic hysterectomy performed for benign indications by a minimally invasive gynecologic surgeon (J.Q.H.). Approval was received from the institutional review board of New York Hospital Queens, New York, USA. Standard technique for the surgeon during these cases included uterine manipulator placement; initial peritoneal insufflation using Veress needle; placement of a 5-mm assist port in the left upper quadrant; placement of a 12-mm umbilical port for the camera; and placement of 3 additional 8-mm ports for the robotic instruments. Uterine specimens were removed vaginally, with vaginal morcellation as necessary. Routine cystoscopy was

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performed at the conclusion of hysterectomy prior to port removal. De-identified patient demographic information—including case number, age at time of surgery, body mass index (BMI, calculated as weight in kilograms divided by the square of height in meters), and prior abdominopelvic surgeries—was abstracted from clinical charts. Perioperative information—including surgical indication, total operative time (defined as time from Veress needle placement to skin closure), specimen weight, and estimated blood loss—was abstracted from in-patient electronic medical records and pathology reports. We were interested in the effects of demographic factors and specimen weight on estimated blood loss (as estimated by the surgeon), total operative time, and post-surgical length of stay. Immediate intraoperative and postoperative complications such as bowel, bladder, ureteral, and vascular injuries; transfusions; and reoperations were also tracked.

Outcome data distribution was tested for normality via the Kolmogorov–Smirnov test, and appropriate univariate tests were applied based on whether the outcome of interest was distributed in a normal (i.e. *t* test, analysis of variance) or non-normal (i.e. Mann–Whitney *U* test, Kruskal–Wallis *H* test) fashion. A multivariable model was developed for each outcome of interest, using multiple linear regression to evaluate the effect of case number on each outcome while controlling for relevant variables.

Given prior data that most learning curves assume a power-law relationship [17,18], we applied a power-law curve model to the abstracted learning data (i.e. outcome vs case number)—both the raw value and the predicted value from the multivariable model—and examined the curves to identify where the learning curve stabilized.

The acceptable α error level was set at $P < 0.05$ with 2-tailed tests. All statistical analyses were performed using SPSS 19.0.0 (IBM, Armonk, NY, USA) and learning data were plotted on and curve fitted in Excel 2010 (Microsoft, Redmond, WA, USA).

3. Results

The 100 procedures were performed over a period of 17 months between May 5, 2010, and September 30, 2011. In the study cohort, mean age at time of surgery was 46 years and mean BMI was 27.8 (Table 1). Fifty-five (55%) patients had undergone prior abdominopelvic surgeries, 17 (31%) of whom had undergone more than 2 prior surgeries. The most common indication for surgery was leiomyoma, followed by menorrhagia and pelvic pain. Median specimen weight was 215 g, median total operative time was 120 minutes, and median estimated blood loss was 100 mL. The majority of patients were discharged on the day of surgery.

Details of univariate analyses of association between demographic/perioperative variables and outcomes of interest are shown in Table 2. Case number ($P = 0.001$) and specimen weight ($P = 0.001$) were significantly associated with total operative time. Case number ($P < 0.001$) and age ($P < 0.05$) were significantly associated with estimated blood loss.

Using the enter method, stepwise multiple linear regression modeling was performed to predict total operative time. Age, BMI, prior abdominopelvic surgery, and uterine weight were entered in the first step, and case number was entered at the second step. The model (adjusted r^2 0.224) achieved statistical significance ($F_{7,\ 81} = 4.630$; $P < 0.001$). Uterine weight (β 0.330; $P < 0.005$) and case number (β-0.296; $P < 0.005$; r^2 change from step 1 = 0.082, $P < 0.003$) were independently associated with operative time.

Table 1
Patient characteristics.[a]

Characteristic	Value
Age, y	46.0 ± 7.4
Body mass index[b]	27.8 ± 7.1
Prior abdominopelvic surgeries	1 (0–4)
Specimen weight, g	215 (62–1878)
Total operative time, min	127 (70–544)
Estimated blood loss, mL	100 (20–1000)
Post-surgical length of stay, d	0 (0–5)

[a] Values are given as mean ± SD or median (range).

[b] Calculated as weight in kilograms divided by the square of height in meters.

Table 2
Surgical parameters.[a]

	Total operative time, min	Estimated blood loss, mL	Post-surgical length of stay, d
Case number			
1–26	189	200	0
27–51	105	100	0
52–76	118	75	0
77–100	120	50	0
P value	<0.005	<0.001	0.933
Age, y			
≤41	134	100	0
42–46	121	75	0
47–50	168	200	0
>50	114	100	0
P value	0.344	<0.05	0.533
Body mass index[b]			
≤19	83.5	75	0
20–25	124.5	100	0
26–30	127.5	125	0
>30	139	75	0
P value	0.211	0.401	0.269
Prior abdominopelvic surgeries			
0	124.5	100	0
1	131.5	100	0
≥2	121	100	0
P value	0.773	0.555	0.703
Specimen weight, g			
≤148	102	75	0
149–215	118	87.5	0
216–418	131	112.5	0
>418	177.5	175	0
P value	<0.005	0.126	0.606

[a] Values are given as median unless otherwise indicated.

[b] Calculated as weight in kilograms divided by the square of height in meters.

A similar model (adjusted r^2 0.109) was developed to predict estimated blood loss. The model achieved statistical significance ($F_{7,\ 80} = 2.519$; $P < 0.05$), with uterine weight (β 0.387; $P < 0.005$) the only significant predictor; case number did not significantly contribute to the model (r^2 change from step 1 = 0.011; $P = 0.305$). Finally, a multiple linear regression model was also developed for post-surgical length of stay; however, this model did not attain statistical significance ($F_{7,\ 81} = 1.288$; $P = 0.267$).

Given these findings, we examined the learning curve effect on total operative time (Fig. 1). The power-law modeling (adjusted r^2 0.123) achieved statistical significance ($F_{1,\ 96} = 14.658$; $P < 0.001$) and can be described by the equation:

$$\mathit{Total\ Operative\ Time} = 278.98 \times (\mathit{Case\ Number})^{-0.182}$$

The derivative function of this power curve, which describes its slope as a function of case number, is described by the equation:

$$\mathrm{d}(\mathit{Total\ Operative\ Time})/\mathrm{dx} = -50.77 \times (\mathit{Case\ Number})^{-1.182}$$

As the slope asymptotically approaches 0, we picked the point at which it crosses –1.0 as the threshold for proficiency; this occurs at case 28.

To control for effects of preoperative factors on operative time, we also performed power-law modeling (adjusted r^2 0.190) on the predicted total operative time obtained previously from the multiple linear regression model (Fig. 2). The equation is:

$$\mathit{Predicted\ Total\ Operative\ Time} = 260.89 \times (\mathit{Case\ Number})^{-0.146}$$