

Hugo RAS versus da Vinci Xi for robot-assisted simple hysterectomy in endometrial cancer: a concurrent-period comparison of operative efficiency, cost structure, and the cost of early adoption

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Abstract

Assessing a newly introduced robotic platform is complicated by structural confounding between platform and calendar time, which makes device-specific performance hard to separate from early-adoption learning. We compared the Hugo robotic-assisted surgery (RAS) system with the da Vinci Xi in robot-assisted simple hysterectomy for endometrial cancer, confining the primary analysis to the period of concurrent use of the two platforms. This single-centre retrospective cohort included 219 patients with clinical stage I endometrial cancer operated between May 2018 and November 2025; procedures involving lymphadenectomy or sentinel lymph node biopsy were excluded at eligibility so that operative time remained comparable. The Hugo RAS was introduced on 4 December 2023, and the standardised mean difference (SMD) for operative month across the full period was 2.10; the primary analysis was therefore limited to 67 concurrent-period procedures (da Vinci Xi 37, Hugo RAS 30; SMD 0.66). Time outcomes were modelled by linear regression and cost outcomes by gamma regression with a log link, both with robust standard errors. In the concurrent period, the adjusted mean difference in total operative time was 16.3 min (95% confidence interval [CI] 6.0–26.6; $p = 0.002$), falling to 6.1 min (95% CI – 0.7 to 13.0; $p = 0.080$) when the first ten Hugo RAS procedures were excluded. Adjusted cost ratios favoured the Hugo RAS for consumables (0.808) and total operative cost (0.923), with no clear difference in reimbursement (1.013). The attenuation after excluding early cases points to an early-adoption contribution that cannot be separated from platform effects.

1 Introduction

Endometrial cancer is usually detected at an early stage, and hysterectomy is the cornerstone of both staging and definitive treatment. In the LAP2 trial, the laparoscopic approach lowered postoperative morbidity and shortened hospital stay relative to laparotomy, at the price of a longer procedure [1]; its long-term follow-up, however, failed to meet the prespecified non-inferiority margin for recurrence [2]. Robotic platforms add wristed instruments, three-dimensional magnified vision, and tremor filtering. In a randomised comparison with conventional laparoscopy for endometrial cancer, perioperative safety was similar, while operative time and theatre occupancy were shorter with the robot [3]. Because robotic systems are expensive to acquire and reports on operative time diverge, their value has to be weighed on perioperative outcomes, theatre logistics, and health economics jointly [4, 5].

Gynaecological evidence on the Hugo RAS is drawn mostly from early adoption series. The first reports described the system architecture together with the port and arm-cart configurations used for gynaecological procedures [6]; subsequent series reported feasibility and acceptable perioperative results, largely in mixed indications or in benign disease such as endometriosis [7, 8]. A recent systematic review drew the same conclusion, namely that the literature is dominated by initial institutional experience [9]. One single-centre study that propensity-score matched the first 40 Hugo RAS procedures to da Vinci Xi procedures found no clear difference in length of stay, blood loss, or perioperative complications, but a longer operative time with the Hugo RAS for endometrial cancer staging [10]. At our own institution, in simple hysterectomy for benign disease, operative time on the

Hugo RAS remained longer once surgeon and operative year were taken into account, whereas total operative cost was lower, mainly because of consumables [11].

A methodological constraint is common to all of these comparisons. Any newly introduced platform is, by necessity, used only in the later part of a study period; platform and calendar time are therefore structurally confounded, and common support is lacking. Regression adjustment for calendar time under these conditions produces estimates that rest on extrapolation from the functional form of the model rather than on observed contrasts [12, 13]. Even if calendar-time confounding could be removed, an asymmetry in the familiarity of surgeons and theatre staff would remain, since cases on the new platform are early ones by definition while those on the established platform are mature. Docking time with the Hugo RAS falls as case experience accumulates [14], and any institution considering adoption needs to separate this learning process from the performance of the device itself.

We therefore compared the two platforms in 219 robot-assisted hysterectomies performed for endometrial cancer at one centre, taking a comparison confined to the period of concurrent use as the primary analysis. We assessed (1) operative efficiency by procedural stage, (2) actual case-level cost and profitability, and (3) how much the early adoption phase contributed. Overlap weighting [15] was applied as a supplementary analysis that secures common support explicitly.

2 Materials and methods

2.1 Setting and study population

This retrospective cohort study was carried out at Yamanashi Central Hospital, a single institution. Patients treated by robot-assisted surgery for endometrial cancer on either the da Vinci Xi or the Hugo RAS between 10 May 2018 and 17 November 2025 were identified, and their clinical data were drawn from the institutional operative register, the electronic medical record, and the hospital accounting database. The da Vinci Xi was available throughout the study period, whereas the Hugo RAS entered clinical use on 4 December 2023. Reporting adheres to STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) [16].

Eligible patients had clinical stage I endometrial cancer on preoperative assessment and underwent robot-assisted simple hysterectomy. Since the study concerns operative efficiency, the population was limited to simple hysterectomy with or without salpingo-oophorectomy, and any procedure that included lymphadenectomy or sentinel lymph node biopsy was excluded at the eligibility stage. Nodal assessment strongly affects operative time and its uptake tracks calendar time, so such cases would have confounded surgical content with platform; this restriction is central to the design.

Among 239 registered procedures, 20 were removed because the final pathology showed atypical endometrial hyperplasia or endometrial intraepithelial neoplasia, showed no malignancy, or was missing, which left 219 procedures in the full-period cohort (da Vinci Xi 189, Hugo RAS 30). Two cases in which the structured pathology field and the free-text note disagreed were kept under a rule fixed in advance,

and a sensitivity analysis omitting them is provided (Online Resource 1). Final pathological stage followed the 2009 staging system of the International Federation of Gynecology and Obstetrics (FIGO), applied in the same way throughout the study period; cases were not restaged under the 2023 revision [17].

2.2 Primary analysis population

The concurrent cohort, defined as procedures performed on or after 4 December 2023, served as the primary analysis population. Across the full period the standardised mean difference (SMD) for operative month was 2.10, so counterfactuals for the period before the Hugo RAS existed could only be extrapolated. When positivity fails, restricting the analysis to the subpopulation in which it holds is the recommended course [12, 13]. The concurrent cohort contained 67 procedures (da Vinci Xi 37, Hugo RAS 30) with overlapping calendar ranges and an operative-month SMD of 0.66. Analyses of the full period are presented for reference.

2.3 Platforms and procedures

Assignment to a platform was not randomised; it depended on device availability and institutional scheduling. Four surgeons contributed procedures over the full period, three of whom contributed to the concurrent cohort. The da Vinci Xi, made by Intuitive Surgical (Sunnyvale, CA, USA), has an integrated patient cart, whereas the Hugo RAS, made by Medtronic (Minneapolis, MN, USA), was docked using separate arm carts. To classify lymph node assessment and adnexal surgery, surgical content was extracted again from the operative register. None of the included procedures had any record of nodal assessment; adnexal surgery was addressed in a sensitivity analysis.

2.4 Variables and outcome definitions

Data were collected on age, body mass index (BMI), uterine weight, surgeon, platform, date of surgery, history of abdominal surgery, and final stage and histology. Timing of surgery entered the models as a continuous calendar-month index counted from the first operative month of the full-period cohort, and uterine weight entered as $\log(\text{weight} + 1)$. No imputation of missing values was performed.

Total operative time was the primary outcome. Secondary outcomes comprised console time, docking time, patient-in-room time, non-console time (calculated as total minus console time), and blood loss. Docking was timed from the skin incision until console operation began; as this interval includes port placement and preparation, we call it incision-to-console time, and it cannot be compared directly with studies that time arm connection alone. A value of 5 mL was recorded for blood loss in 187 of 219 procedures, a floor effect of the recording convention, so blood loss was analysed as a binary outcome (more than 5 mL). The dataset has no structured fields for intraoperative adverse events, readmission, transfusion, conversion, or length of stay, so complications could not be assessed.

Cost outcomes, expressed per case in Japanese yen and obtained from the hospital accounting database, were total operative cost, consumable cost, reimbursement, profit, and profit margin. The analysis takes the provider's perspective: reimbursement is set by the Japanese fee schedule, so a lower

cost to the hospital does not translate into lower public expenditure. Profit and profit margin are functions of reimbursement and operative cost. Operative cost comprises consumable, labour, drug, and overhead components, and in every case these components summed exactly to the recorded total. Capital items, including depreciation of the purchase price and maintenance contracts, are not recorded separately, so total cost of ownership cannot be derived from this analysis. Of the 187 cases with complete cost records, one with zero reimbursement and two identified as internally inconsistent by an external cost-accounting review were removed, leaving 61 concurrent-period cases (36 and 25).

Recurrence was taken as recurrence documented by imaging, pathology, or the treating physician's note, and recurrence-free survival (RFS) was timed from the day of surgery; death could not be used as an event. Only six recurrences occurred in the concurrent cohort (4 and 2), so no time-to-event analysis was undertaken in that cohort. For the full-period cohort, Kaplan–Meier estimates of RFS and the median follow-up (reverse Kaplan–Meier method [18]) are presented descriptively and without log-rank testing, because a non-significant test between groups whose follow-up differs fundamentally reflects a lack of comparative information rather than an absence of difference.

2.5 Statistical methods

Descriptive statistics are the mean $\pm$ standard deviation (SD) and the median [interquartile range (IQR)] for continuous variables, counts (%) for categorical variables, and the SMD for imbalance between groups. For the time outcomes, mean differences were obtained from linear regression models with platform, age, BMI, log(uterine weight + 1), history of abdominal surgery, surgeon (fixed effects), and the calendar-month index as covariates, with heteroscedasticity-consistent type 3 (HC3) standard errors. Because cost outcomes are positive and right-skewed, they were modelled with gamma regression and a log link using the same covariate set and HC3 errors; effects are reported as adjusted ratios (Hugo RAS relative to da Vinci Xi) and as adjusted absolute differences in yen derived from standardised predictions with delta-method intervals. Linear regression was used for profit margin.

Given 67 cases and 58 residual degrees of freedom, normal reference values combined with HC3 errors can be anti-conservative. We therefore calculated three intervals for every estimate, namely HC3 normal, HC3- $t(n - k)$, and a platform-stratified case bootstrap (2000 replicates), and we flag any outcome on which they disagree (Online Resource 1, Table S3). As a supplementary approach that enforces common support explicitly, overlap weighting [15] was applied to the 218 full-period cases under two propensity score specifications, PS-A (case mix only) and PS-B (case mix plus calendar month). Sensitivity analyses varied the covariate set, the estimator, and the exclusion rules; full specifications are given in Online Resource 1.

Two-sided tests with a 0.05 threshold were used throughout. No multiplicity correction was applied, and p values for secondary outcomes should be read as exploratory. Python 3.13.9 was used for all analyses (pandas 2.3.3, numpy 2.3.5, statsmodels 0.14.6, scipy 1.16.3), and Figs. 1 and 2 were drawn with Matplotlib 3.10.6.

2.6 Ethics and use of artificial intelligence

Ethical approval was granted by the institutional review board of Yamanashi Central Hospital (nos. 2022-09 and 2022-51). Every patient had given written consent to the research use and academic publication of their clinical data. The study involved no additional intervention or specimen collection, and the analysis dataset was held in a form that does not directly identify any individual.

A large language model (Claude, Anthropic) assisted with translating a Japanese draft written by the authors and with language editing. The model generated no data, performed no analysis, and interpreted no results. Every output was checked by the authors, who bear full responsibility for the content.

3 Results

3.1 Cohorts and baseline characteristics

After exclusion of 20 of the 239 procedures assessed, the full-period cohort comprised 219 procedures (da Vinci Xi 189, Hugo RAS 30) performed between 10 May 2018 and 17 November 2025, with an operative-month SMD of 2.100. Restriction to the concurrent period left 67 procedures (da Vinci Xi 37, Hugo RAS 30); in this cohort the operative-month SMD fell to 0.663 and the calendar ranges of the two groups overlapped (Fig. 1). Cost analysis was possible for 61 of these procedures (36 and 25).

The two groups were broadly comparable in age, BMI, uterine weight, history of abdominal surgery, and bilateral salpingo-oophorectomy (Table 1). Imbalance persisted for operative month (SMD 0.663), for the distribution of surgeons, and for several categories of stage, histology, and adnexal surgery.

Hysterectomy was accompanied by bilateral salpingo-oophorectomy in 33 (89.2%) and 27 (90.0%) cases (SMD 0.027). No procedure included lymphadenectomy or sentinel node biopsy. Stage II was confined to the da Vinci Xi group (3 cases) and stage IIIA to the Hugo RAS group (1 case); neither was entered as a covariate.

Table 1
Concurrent cohort: baseline characteristics (n = 67)

Variable	Level / summary	da Vinci Xi (n = 37)	Hugo RAS (n = 30)	SMD
Age, years	Mean ± SD; median [IQR]	57.1 ± 13.2; 54.0 [50.0, 63.0]	58.1 ± 14.5; 55.5 [50.0, 70.2]	0.071
BMI, kg/m ²	Mean ± SD; median [IQR]	26.9 ± 6.4; 25.6 [22.9, 28.4]	27.1 ± 7.5; 24.9 [22.2, 31.4]	0.042
Uterine weight, g	Mean ± SD; median [IQR]	170.1 ± 139.6; 125.0 [95.0, 198.0]	146.6 ± 68.1; 142.0 [91.2, 195.2]	0.213
Previous abdominal surgery	Yes	11 (29.7)	7 (23.3)	0.145
Adnexal surgery	Bilateral	33 (89.2)	27 (90.0)	0.027
Adnexal surgery	Unilateral	4 (10.8)	1 (3.3)	0.295
Adnexal surgery	None	0 (0.0)	2 (6.7)	0.378
Lymph node assessment	Lymphadenectomy or sentinel biopsy	0 (0.0)	0 (0.0)	—
Operative month	Median [IQR]	2024-07 [2024-04, 2024-10]	2025-02 [2024-07, 2025-08]	0.663
Surgeon	A	23 (62.2)	23 (76.7)	0.319
Surgeon	B	8 (21.6)	3 (10.0)	0.323
Surgeon	C	6 (16.2)	4 (13.3)	0.081
Surgeon	D	0 (0.0)	0 (0.0)	0.000
FIGO stage	IA	27 (73.0)	25 (83.3)	0.253
FIGO stage	IB	7 (18.9)	4 (13.3)	0.152
FIGO stage	II	3 (8.1)	0 (0.0)	0.420
FIGO stage	IIIA	0 (0.0)	1 (3.3)	0.263
Histology	Endometrioid G1	30 (81.1)	21 (70.0)	0.260

The concurrent cohort consists of procedures performed on or after 4 December 2023. Entries are mean ± SD with median [IQR] for continuous variables and n (%) for categorical variables. Extent of adnexal surgery and lymph node assessment were retrieved retrospectively from the operative register and verified for all 67 concurrent-period procedures. In the full-period cohort the operative-month SMD was 2.100. Surgeon D, clear cell carcinoma, and mixed histology contributed no case to the concurrent cohort. FIGO stage II (3/0) and IIIA (0/1) occur in one group only and were not used as covariates. BMI body mass index, IQR interquartile range, SD standard deviation, SMD standardised mean difference

Variable	Level / summary	da Vinci Xi (n = 37)	Hugo RAS (n = 30)	SMD
Histology	Endometrioid G2	5 (13.5)	6 (20.0)	0.174
Histology	Endometrioid G3	0 (0.0)	1 (3.3)	0.263
Histology	Serous	1 (2.7)	1 (3.3)	0.037
Histology	Carcinosarcoma	1 (2.7)	1 (3.3)	0.037
The concurrent cohort consists of procedures performed on or after 4 December 2023. Entries are mean $\pm$ SD with median [IQR] for continuous variables and n (%) for categorical variables. Extent of adnexal surgery and lymph node assessment were retrieved retrospectively from the operative register and verified for all 67 concurrent-period procedures. In the full-period cohort the operative-month SMD was 2.100. Surgeon D, clear cell carcinoma, and mixed histology contributed no case to the concurrent cohort. FIGO stage II (3/0) and IIIA (0/1) occur in one group only and were not used as covariates. BMI body mass index, IQR interquartile range, SD standard deviation, SMD standardised mean difference				

3.2 Time outcomes and blood loss

Table 2 lists the time outcomes and blood loss for the concurrent cohort. Mean total operative time was 70.2 ± 22.9 min on the da Vinci Xi and 81.1 ± 22.0 min on the Hugo RAS. The unadjusted mean difference was 10.8 min (95% CI – 0.1 to 21.8; $p = 0.053$), and after adjustment the difference was 16.3 min (95% CI 6.0–26.6; $p = 0.002$, $n = 67$). Zero was also excluded by the HC3-t(58) interval (5.8–26.8) and by the bootstrap interval (7.5–25.2).

Table 2
Time outcomes and blood loss, concurrent cohort (n = 67)

Outcome	da Vinci Xi	Hugo RAS	Unadjusted effect (95% CI)	Adjusted effect (95% CI)	n
Total operative time, min	70.2 ± 22.9; 64.0 [53.0–84.0]	81.1 ± 22.0; 75.0 [65.8–94.0]	+ 10.8 (– 0.1 to 21.8); p = 0.053	+ 16.3 (6.0–26.6); p = 0.002	67
Console time, min	48.6 ± 19.5; 41.5 [34.0–62.8]	54.4 ± 16.7; 49.0 [40.2–69.0]	+ 5.9 (– 3.0 to 14.7); p = 0.196	+ 10.0 (4.0–15.9); p = 0.001	66
Non-console time, min	20.9 ± 6.9; 19.5 [15.8–25.0]	26.6 ± 10.9; 23.5 [21.0–28.5]	+ 5.7 (1.1–10.3); p = 0.015	+ 6.5 (0.1–13.0); p = 0.046 ^a	66
Incision-to-console time, min	9.4 ± 3.9; 8.0 [7.0–11.0]	13.8 ± 6.0; 11.5 [9.0–16.8]	+ 4.4 (1.8–6.9); p < 0.001	+ 4.4 (1.0–7.7); p = 0.011	66
Patient-in-room time, min	116.2 ± 26.8; 110.0 [91.2–133.5]	135.0 ± 29.4; 134.0 [112.5–154.0]	+ 18.8 (4.4–33.2); p = 0.010	+ 20.3 (8.5–32.1); p < 0.001	63
Blood loss > 5 mL, n (%)	2 (5.4)	2 (6.7)	Exact OR 1.25 (0.09–18.20); p = 1.00	Not analysed	—
Surgical complications	Not assessable	Not assessable	—	—	—
Time effects are mean differences (Hugo RAS – da Vinci Xi) from models with age, BMI, log(uterine weight + 1), history of abdominal surgery, surgeon fixed effects, and the calendar-month index as covariates, with HC3 robust standard errors. Fisher's exact test was used for blood loss. Surgical complications could not be assessed because intraoperative adverse events are not recorded as structured data. ^a For non-console time, the HC3-t(57) interval (– 0.02 to 13.10) contains zero, and the three intervals disagree on significance (Online Resource 1, Table S3). CI confidence interval, OR odds ratio; n number of cases in the adjusted model					

Broken down by stage, the adjusted differences were 10.0 min for console time (95% CI 4.0–15.9), 6.5 min for non-console time (0.1–13.0), 4.4 min for incision-to-console time (1.0–7.7), and 20.3 min for patient-in-room time (8.5–32.1), each longer on the Hugo RAS. For non-console time, however, the three intervals did not agree: the HC3-t(57) interval (– 0.02 to 13.10) contained zero whereas the HC3 normal and bootstrap intervals did not, so significance depends on the reference distribution and the result is not definitive.

Blood loss above 5 mL was recorded in 2 (5.4%) and 2 (6.7%) cases (exact odds ratio 1.25, 95% CI 0.09–18.20; Fisher's exact p = 1.00). Among da Vinci Xi cases across the full period the corresponding proportion was 15.9% (30/189), suggesting that the apparent blood-loss difference in full-period

comparisons reflects calendar time rather than platform. As noted above, surgical complications could not be assessed.

3.3 Contribution of the early adoption phase

Figure 2 and Table 3 present the estimates obtained under each analysis design. When the first ten Hugo RAS procedures were excluded, the adjusted mean difference fell from 16.3 to 6.1 min (95% CI – 0.7 to 13.0; $p = 0.080$, $n = 57$). Such attenuation is compatible with a contribution from early adoption, although it does not isolate a causal learning effect.

Table 3
Primary outcome estimates under each analysis design

Analysis design	n	Effect (min)	95% CI	p
Concurrent cohort, adjusted (primary analysis)	67	+ 16.31	6.04 to 26.58	0.002
Concurrent cohort, unadjusted	67	+ 10.82	–0.14 to 21.79	0.053
Concurrent cohort, calendar month removed	67	+ 15.48	7.89 to 23.08	< 0.001
Concurrent cohort, reduced covariate set	67	+ 10.99	–0.42 to 22.40	0.059
Concurrent cohort, first 10 Hugo RAS cases excluded	57	+ 6.12	–0.74 to 12.99	0.080
Concurrent cohort, adnexal surgery added as covariate	67	+ 16.37	5.97 to 26.77	0.002
Concurrent cohort, surgeon A only	46	+ 19.29	6.61 to 31.96	0.003
Concurrent cohort, Huber M-estimation	67	+ 11.62	5.10 to 18.14	< 0.001
Concurrent cohort, median regression	67	+ 8.57	0.99 to 16.15	0.027
Concurrent cohort, gamma log (standardised absolute difference)	67	+ 18.16	7.14 to 29.18	< 0.001
Full-period cohort, unadjusted (reference)	219	–4.02	–13.08 to 5.04	0.384
Full-period cohort, adjusted (reference)	218	+ 14.04	4.69–23.39	0.003
Change produced by adjustment: full-period cohort + 18.06 min; concurrent cohort + 5.49 min. All effects are mean differences except median regression, which gives a conditional median difference. CI confidence interval				

The estimate was stable across specifications (Table 3): 15.5 min without the calendar-month index, 19.3 min when restricted to surgeon A, 11.6 min with Huber M-estimation, 8.6 min with median regression, and 18.2 min for the standardised difference from the gamma log model. Including the

extent of adnexal surgery as a covariate yielded 16.4 min (95% CI 6.0–26.8), so the small residual difference in surgical content does not account for the time difference.

In the full-period cohort, adjustment that included calendar month shifted the estimate from – 4.0 to + 14.0 min, a change of 18.1 min; in the concurrent cohort the corresponding shift was from 10.8 to 16.3 min, a change of 5.5 min. The smaller shift after restriction to the concurrent period is consistent with less dependence on extrapolation, although residual confounding cannot be excluded. The two adjusted estimates pointed in the same direction.

The supplementary overlap-weighted analysis (Online Resource 1, Table S2 and Figs. S1, S2) gave a consistent picture. With PS-A, which leaves out calendar month, the estimate was – 3.5 min (95% CI – 12.7 to 5.6; $p = 0.448$), close to the unadjusted full-period value; with PS-B, which includes it, the estimate was 15.9 min (95% CI 3.2–28.5; $p = 0.014$), and trimming at 0.05 and 0.10 gave 16.3 min ($n = 71$) and 16.5 min ($n = 65$). The 65 cases retained after trimming corresponded closely to the 67-case concurrent cohort defined by calendar period. Balance diagnostics after weighting nevertheless exposed a limitation: PS-B reduced the weighted SMD for operative month from 2.10 to 0.00 but increased the SMD for platform-specific cumulative case number from 2.02 to 4.09, and balance worsened on eight variables altogether. The more closely calendar time is aligned, the more the comparison reduces to early Hugo RAS cases against mature da Vinci Xi cases, so the PS-B estimate still represents an early-adoption comparison rather than an isolated device effect.

3.4 Cost outcomes

Table 4 gives the cost results for the concurrent cohort. The adjusted ratio for operative cost was 0.923 (95% CI 0.857–0.993; $p = 0.031$), corresponding to an absolute difference of –¥28,023 (95% CI – 53,333 to – 2,713); for consumable cost the ratio was 0.808 (95% CI 0.730–0.895; $p < 0.001$), corresponding to – ¥50,928 (95% CI – 75,607 to – 26,249). For reimbursement no clear difference emerged (ratio 1.013, 95% CI 0.987–1.041; $p = 0.332$). Profit (ratio 1.076, 95% CI 1.005–1.151) and profit margin (difference 3.70 percentage points, 95% CI 0.48–6.92) are linked financial measures, each derived from reimbursement and operative cost, and do not constitute independent evidence of a cost benefit.

Table 4
Cost outcomes, concurrent cohort (n = 61)

Outcome	da Vinci Xi (n = 36)	Hugo RAS (n = 25)	Adjusted effect (95% CI)	Adjusted absolute difference (95% CI)	p
Operative cost, ¥	365,641 ± 45,141	328,618 ± 48,553	Ratio 0.923 (0.857–0.993)	–28,023 (– 53,333 to – 2,713)	0.031
Consumable cost, ¥	266,942 ± 50,587	213,141 ± 44,324	Ratio 0.808 (0.730–0.895)	–50,928 (– 75,607 to – 26,249)	< 0.001
Reimbursement, ¥	852,964 ± 45,705	860,696 ± 39,155	Ratio 1.013 (0.987–1.041)	+ 11,339 (– 11,593 to 34,270)	0.332
Profit, ¥ ^a	487,323 ± 61,363	532,078 ± 63,719	Ratio 1.076 (1.005–1.151)	+ 37,184 (2,614–71,754)	0.035
Profit margin, % ^a	57.0 ± 5.8	61.7 ± 6.4	Difference + 3.70 points (0.48–6.92)	+ 3.70 points (0.48–6.92)	0.024
Non-consumable cost, ¥ ^b	98,699	115,477	–	+ 22,905 (adjusted, derived)	–
Monetary outcomes are ratios (Hugo RAS / da Vinci Xi) from gamma regression with a log link; absolute differences come from standardised predictions with the delta method. The analysis takes the provider's perspective. ^a Profit = reimbursement – operative cost and profit margin = profit / reimbursement; both are functions of reimbursement and operative cost and are therefore related rather than independent outcomes. Ratios and absolute differences were estimated in separate models and need not satisfy an exact additive identity. ^b Non-consumable cost = operative cost – consumable cost. Group values are approximate differences of rounded unadjusted means; the adjusted value is the difference between the adjusted absolute differences for total cost and consumable cost.					

Unadjusted non-consumable cost (Online Resource 1, Table S1) was about ¥98,699 on the da Vinci Xi and ¥115,477 on the Hugo RAS. Subtracting the consumable cost difference from the total cost difference, each modelled separately, yields a derived non-consumable difference of +¥22,905 for the Hugo RAS; this figure is not a directly fitted estimate. Lower consumable costs thus went together with longer operating times. Overlap-weighted PS-B estimates pointed the same way (consumable ratio 0.819, 95% CI 0.719–0.934; operative cost ratio 0.928, 95% CI 0.853–1.011).

3.5 Oncologic outcomes

Across the full period, recurrence occurred in 18 of 189 da Vinci Xi and 2 of 30 Hugo RAS cases, with a median follow-up (reverse Kaplan–Meier) of 47.2 and 14.8 months. RFS at 24 months was estimated at 91.9% (95% CI 86.9–95.0) and 90.0% (95% CI 63.8–97.6), and no Hugo RAS patient remained at risk at

36 months (Online Resource 1, Table S4 and Fig. S3). Given the fundamentally different follow-up of the two groups, no between-group test was carried out, and these estimates do not address oncologic equivalence or non-inferiority.

4 Discussion

Confining the procedure to simple hysterectomy without nodal assessment narrowed the variation in surgical content, and confining the primary comparison to the period of concurrent use reduced, though did not remove, the imbalance in calendar time. Adding adnexal surgery to the adjustment set moved the total operative-time difference only from 16.3 to 16.4 min.

In the primary analysis, total operative time was 16.3 min longer on the Hugo RAS. Positive estimates were likewise obtained with alternative covariate sets, Huber regression, median regression, gamma regression, and PS-B overlap weighting, although the confidence interval of the reduced-covariate estimate crossed zero (– 0.42 to 22.40 min). The direction of the effect was therefore consistent across analyses, whereas statistical significance was not universal.

Omitting the first ten Hugo RAS procedures reduced the difference to 6.1 min, with an interval that crossed zero. This argues for taking early adoption into account when platform comparisons are interpreted, but exclusion alters the case mix and the calendar distribution as well as experience. Every Hugo RAS procedure was among the first 30 on that platform, whereas the concurrent da Vinci Xi procedures came after more than 150 earlier ones. PS-B weighting balanced calendar month at the price of widening the imbalance in platform-specific case number from 2.02 to 4.09. Neither restriction nor weighting, then, succeeded in separating learning from platform performance.

Despite the longer operative time, consumable and total operative costs were lower on the Hugo RAS. The estimated saving on consumables (¥50,928) was larger than the saving in total cost (¥28,023), which implies a partial offset from other cost components. These results describe the cost structure as observed; they do not show that the cost difference is independent of learning. No clear difference in reimbursement was found, and a lower cost to the hospital should not be read as a lower cost to the payer.

An earlier comparison in endometrial cancer staging also reported longer operative time with the Hugo RAS, without clear differences in blood loss or complications [10]. In our institution's series of 327 simple hysterectomies for benign disease, the adjusted ratios were 0.83 (total surgical cost) and 0.75 (material cost), whereas operative time and console time were longer by 9.4 and 5.6 min, respectively [11]. The directions agree, but the two studies share surgeons, theatre teams, procurement contracts, and accounting practices, so their concordance reflects a common institutional setting rather than independent external replication.

A published cumulative summation analysis reports that docking time with the Hugo RAS decreases with experience [14]. Our incision-to-console difference of 4.4 min encompasses port placement and

preparation and cannot be set directly against docking time alone. The largest stage-specific difference was in console time (10.0 min), which suggests that preparation by itself does not explain the observed difference in operative time.

Decisions on adoption should weigh operative time, consumable prices, theatre capacity, and capital cost together. Here, savings on consumables coexisted with a longer patient-in-room time (20.3 min). Extra theatre occupancy may have consequences for staff workload and capacity that were not measured directly. Without acquisition, maintenance, and opportunity costs, the net benefit to the institution cannot be determined.

Several limitations qualify the interpretation. Platform and early experience remain inseparable, and excluding ten procedures cannot establish steady-state performance. The data do not support oncologic comparison: the concurrent cohort contained six recurrences, and median follow-up on the Hugo RAS was 14.8 months. Adjuvant treatment and molecular classification (POLE, mismatch repair, and p53 status) were not available, so stratification by molecularly defined risk groups was not possible [19]. The relation between surgical platform and recurrence or survival has been examined elsewhere [20], but our descriptive estimates cannot demonstrate oncologic equivalence. Safety likewise could not be assessed, as structured data on complications, readmission, transfusion, conversion, and length of stay were lacking. The cost findings are contingent on procurement, contracts, volume, and the Japanese fee schedule, and usable concurrent cost data existed for only 25 Hugo RAS procedures. The adjusted reduction in consumable cost of roughly 19.2% may reflect device pricing or market-entry terms, and capital costs were not identified separately. Finally, the primary cohort contained 67 procedures and nine model parameters with no prespecified sample-size calculation; secondary tests were not corrected for multiplicity, inference for non-console time depended on the reference distribution, and 32 of 219 procedures (14.6%) lacked complete cost data, with no examination of missingness by calendar time.

Future work should evaluate performance once more Hugo RAS cases have accumulated, report capital and annual unit costs, and examine safety and oncologic outcomes with adequate follow-up and adjustment for disease characteristics and adjuvant treatment. Multicentre studies that include nodal assessment will be required to establish external validity.

5 Conclusion

Among 67 concurrent-period procedures for endometrial cancer consisting of simple hysterectomy without nodal assessment, total operative time was 16.3 min longer on the Hugo RAS than on the da Vinci Xi. The difference fell to 6.1 min once the first ten Hugo RAS procedures were excluded, which is consistent with an early-adoption contribution that cannot be disentangled from platform and temporal effects. Ratios for consumable and operative cost were 0.808 and 0.923 despite the longer operating time. These findings favour assessing operative efficiency and cost structure jointly during platform adoption.

Declarations

Competing interests

The authors have no financial or non-financial competing interests to declare in relation to this study. For transparency, I.S. was earlier the recipient of an unrestricted Intuitive Foundation research grant (V-20211222), which funded a separate and unrelated study of team-based learning curves in robot-assisted hysterectomy.

Ethics approval

Ethical approval was granted by the institutional review board of Yamanashi Central Hospital on 11 May 2022 (no. 2022-09); extension of the study period to include Hugo RAS cases was approved on 17 March 2023 (no. 2022-51). The study conformed to the ethical standards of the 1964 Declaration of Helsinki and its subsequent amendments.

Consent to participate

Each patient gave written consent to the research use and academic publication of their clinical data.

Consent to publish

Not applicable; no individually identifiable data are included in the manuscript.

Supplementary information

Online Resource 1 Supplementary methods, overlap-weighted estimates with balance diagnostics, small-sample confidence intervals, descriptive recurrence outcomes, and Figs. S1–S3

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Author Contribution

Author contributions Conceptualization: I.S.; Methodology: I.S.; Formal analysis: I.S.; Investigation: All authors; Data curation: I.S.; Writing—original draft: I.S.; Writing—review & editing: All authors; Supervision: T.N.

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Data availability

Requests for the deidentified dataset and analysis outputs should be addressed to the corresponding author and will be considered within institutional and ethical constraints.

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Figures

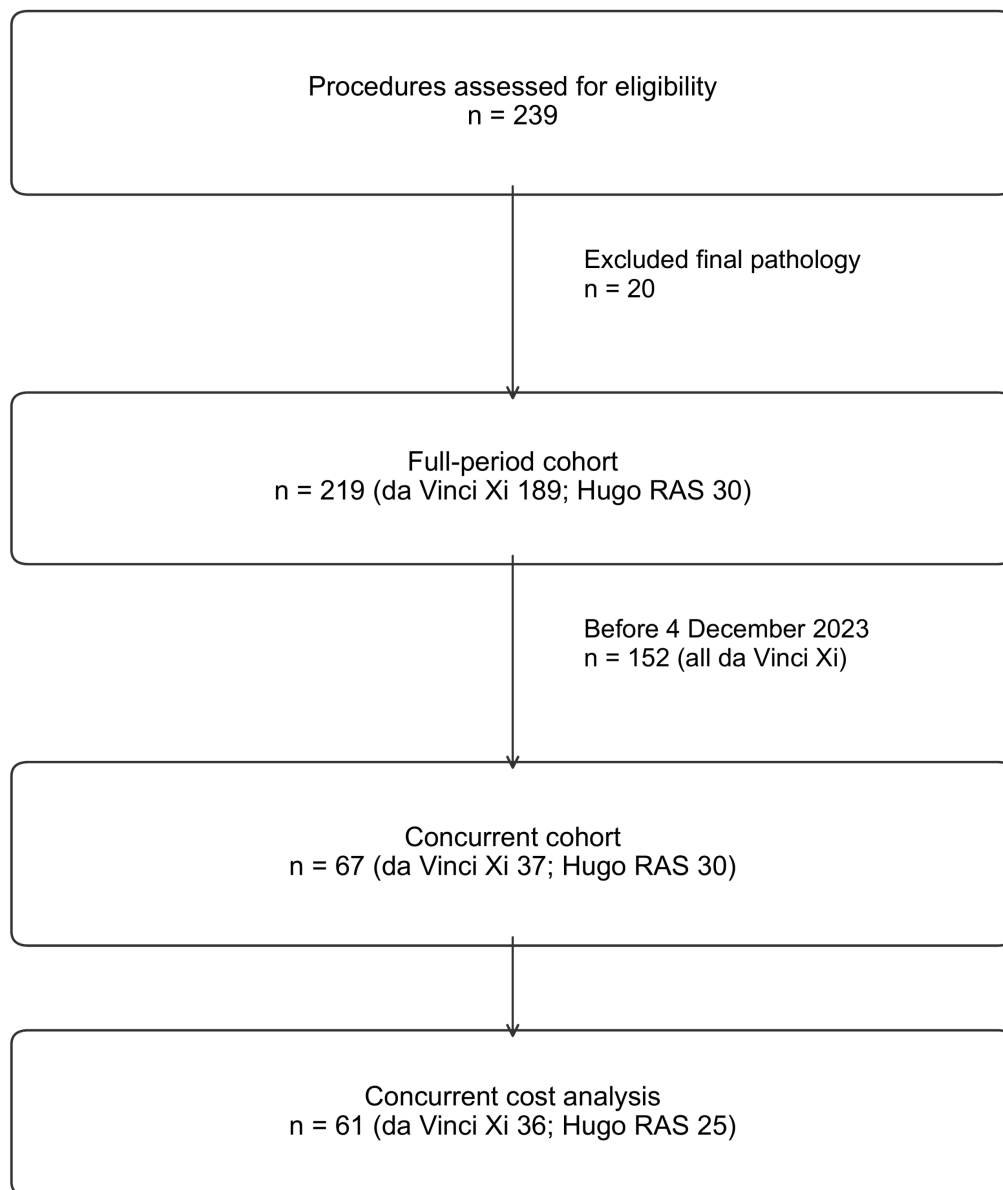


Figure 1

Selection of patients and derivation of the concurrent cohort. Of the 219 procedures in the full-period cohort, 152 performed before the Hugo RAS was introduced on 4 December 2023 (all da Vinci Xi) were removed, leaving 67 procedures (da Vinci Xi 37, Hugo RAS 30) as the concurrent cohort and primary analysis population. Cost analysis included 61 procedures

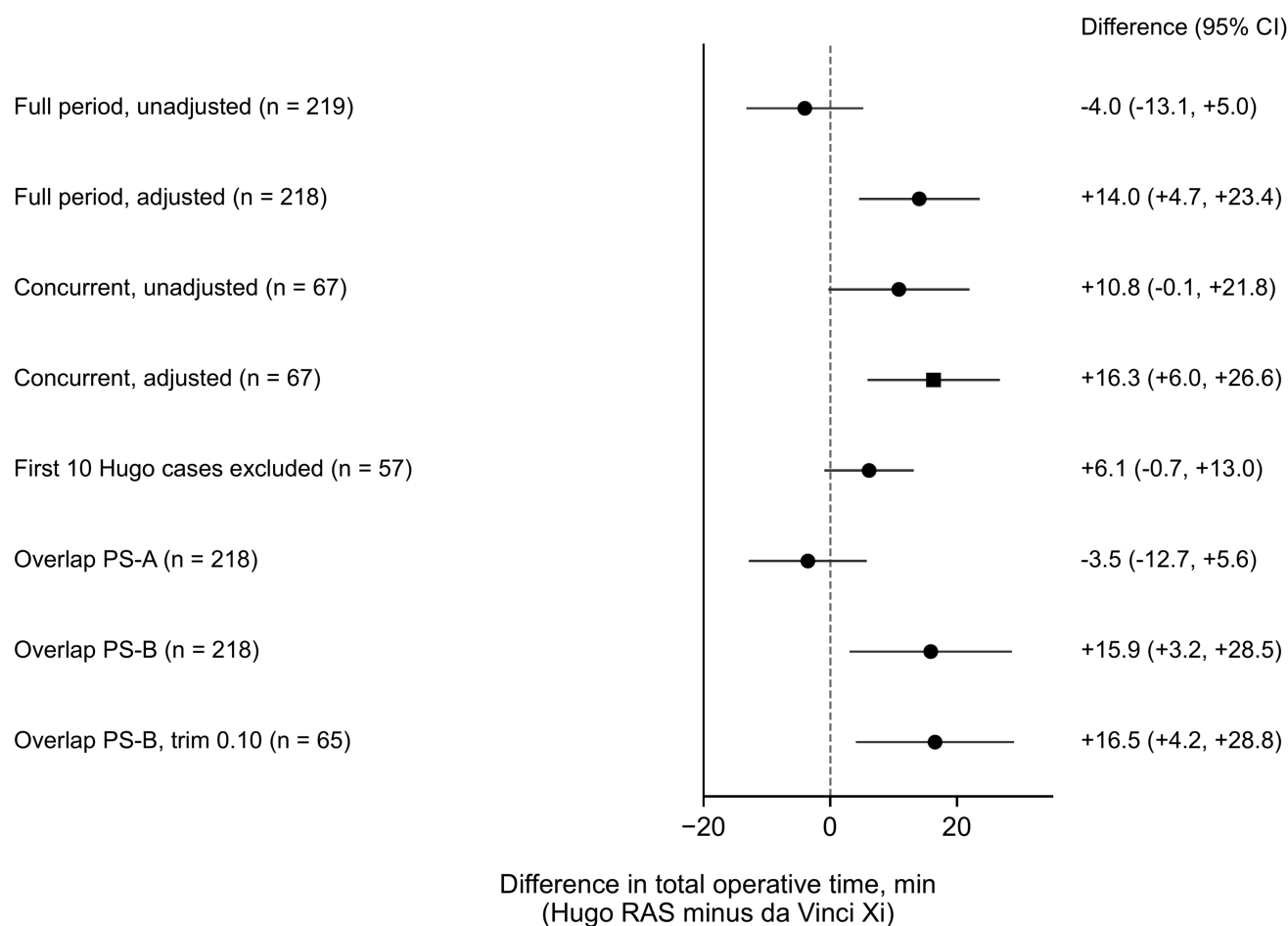


Figure 2

Forest plot of the mean difference in total operative time under each analysis design. Estimates shown are the unadjusted and adjusted values for the full-period cohort, the unadjusted and adjusted values for the concurrent cohort, the value obtained after excluding the first ten Hugo RAS procedures, and the overlap-weighted values (PS-A, PS-B, and PS-B trimmed at 0.10). The dashed line indicates zero. The primary estimate is drawn as a square and the others as circles; horizontal bars are 95% confidence intervals. PS propensity score

Supplementary Files

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