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Comparative Analysis of Robotic, Laparoscopic, and Open Adrenalectomies for Phaeochromocytomas

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Abstract

Background: This study compared outcomes of robotic adrenalectomy (RA), laparoscopic adrenalectomy (LA), and open adrenalectomy (OA) for phaeochromocytoma, focusing on intraoperative haemodynamic stability and perioperative results.

Methods: We conducted a retrospective cohort study at a single tertiary referral centre (2019–2024). All consecutive adults undergoing RA, LA, or OA for phaeochromocytoma were included. RA was performed with the Da Vinci Xi system after programme establishment. The surgical approach was selected by the consultant surgeon according to tumour characteristics and patient factors; OA was generally reserved for suspected malignancy or tumours >10 cm. Diagnosis was confirmed preoperatively with plasma and/or urinary catecholamines. The primary outcome was haemodynamic stability, assessed as the intraoperative mean arterial pressure (MAP) variability (maximum–minimum). Secondary outcomes included operating time, conversion, length of stay (LOS), complications (Clavien–Dindo), and transfusion. Standard statistical tests were applied with two-sided significance set at 0.05.

Results: Sixty-four patients were included (RA=21, LA=38, OA=5). Mean MAP variability was lower with RA than LA (40.3 vs 50. mmHg; p=0.064) and similar to OA (37.9mmHg). RA had the shortest operating time (61.3 ± 31.4min) compared with LA (104.2 ± 36.0min) and OA (187.9 ± 102.0min; p<0.001). Conversion occurred in 5% of RA and 3% of LA cases. LOS was shorter after RA (1.81 days) than LA (3.67 days; p<0.05) and OA (8.80 days; p<0.05). Complication rates were 5% (RA), 8% (LA), and 43% (OA; p=0.015). Transfusion was required in 0% (RA), 2.6% (LA), and 40% (OA; p=0.001).

Conclusions: Robotic adrenalectomy using the Da Vinci Xi system was associated with shorter operating time, reduced hospital stay, and fewer complications than laparoscopic and open surgery. Although the difference in haemodynamic stability did not reach statistical significance, RA showed a favourable trend and no transfusion requirement, supporting its safe and effective use for phaeochromocytoma in appropriately selected patients.

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Introduction

Phaeochromocytoma is an uncommon neuroendocrine tumour originating from the chromaffin cells of the adrenal medulla, which often secretes catecholamines such as epinephrine, norepinephrine, and dopamine. Surgical intervention is the primary treatment for phaeochromocytoma and is considered the only definitive curative approach. The main surgical complications associated with phaeochromocytoma are generally linked to severe perioperative haemodynamic instability.

Observational studies and literature reviews indicate that laparoscopic adrenalectomy offers several advantages over open adrenalectomy, including reduced intraoperative blood loss, less perioperative pain, shorter operating times, shorter hospital stays, and earlier recovery[1]. Recently, robotic surgery has emerged as an alternative minimally invasive approach and robotic adrenalectomy (RA) has emerged as a promising alternative to laparoscopic and open approaches for managing adrenal tumours[2]. However, there is a lack of comprehensive data on the efficacy and safety of robotic adrenalectomy specifically for phaeochromocytoma.

Recent literature suggests that the rate of severe complications, blood loss and transfusion requirements may be lower with robotic surgery[3-5]. While laparoscopic adrenalectomy (LA) remains the gold standard for the surgical management of benign and small adrenal tumours, RA has been shown to be a safe and feasible alternative with comparable intraoperative and postoperative outcome. RA may offer advantages over LA in terms of reduced intraoperative blood loss, shorter time to first flatus, and reduced length of hospital stay[6]. Additionally, robotic-assisted adrenalectomy demonstrates better conversion-to-open rates and operating times compared to laparoscopic approaches[7].

This study examined the role of robotic adrenalectomy compared with laparoscopic and open approaches in the surgical management of phaeochromocytoma. The primary outcome assessed was intraoperative haemodynamic stability, measured through mean arterial pressure variation. The analysis aimed to determine whether the robotic technique, performed using the Da Vinci Xi system, offered measurable advantages in safety, efficiency, or recovery when compared with conventional laparoscopic and open procedures.

Methods

Study Design

This was a retrospective observational study conducted at a single tertiary referral centre. The Newcastle Hospitals NHS Foundation Trust Research Ethics Committee has confirmed that no ethical approval was required.

Patient Selection

Data from all consecutive adult patients who underwent open, laparoscopic (transabdominal) and robotic surgery for phaeochromocytoma between 2019 and 2024 at a tertiary referral centre for phaeochromocytomas, were retrospectively reviewed from a prospectively maintained database. This dataset included information from three consultant surgeons affiliated with the centre.

The diagnosis of phaeochromocytoma was confirmed before surgery using plasma and/or urinary catecholamines. Patient data collected encompassed sex, age, ASA classification, and BMI. Tumour-specific details, such as size and location were also documented.

Surgical Procedures

Surgical approach was determined by the treating consultant surgeon, based on preoperative clinical and radiological assessment. Open adrenalectomy was typically reserved for cases with radiological features concerning for malignancy, including local invasion, or large tumours exceeding 10cm in diameter. A minimally invasive approach was preferred for most phaeochromocytomas.

All minimally invasive adrenalectomies prior to 2022 were performed laparoscopically. In 2022, the Da Vinci Xi Robotic Surgical System was introduced by one of the three consultant surgeons. During the learning curve's initial phase, phaeochromocytomas were excluded from robotic surgery. The consultant surgeon had reached the mastery phase of the learning curve (having completed 90 laparoscopic adrenalectomies) before starting robotic adrenalectomies for phaeochromocytoma. Robotic adrenalectomy was then selectively offered to patients with radiologically benign large tumours, those with elevated BMI, or those without imaging evidence of local invasion.

Postoperatively, it was standard protocol for all patients undergoing surgery for phaeochromocytoma to be admitted to the high dependency unit. Operative details were recorded, including operating time, the planned surgical procedure, and whether conversion to open surgery was necessary.

Outcome Measures

The primary outcome was intraoperative haemodynamic stability, assessed using anaesthetic and electronic records. This was quantified as the difference between the highest and lowest mean arterial pressures (MAP) recorded during surgery. Additional intraoperative variables included the requirement for inotropic support and any episodes of systolic blood pressure exceeding 180 mmHg. Secondary outcome measures comprised length of hospital stay, postoperative complications graded according to the Clavien-Dindo classification, and the need for blood transfusion.

Statistical Analysis

For statistical analysis, categorical variables were compared using Chi-Square tests, with Pearson values, degrees of freedom, and exact p-values provided. Pairwise comparisons of continuous variables were performed using the Least Significant Difference method and Bonferroni correction to adjust for multiple comparisons. Confidence intervals were provided for the primary analyses, and p-values were reported to three decimal places for all tests. All statistical analysis was conducted using a significance level of 0.05 using SPSS version 26.0 (IBM Corp., Armonk, NY).

Results

Patient Demographics

A total of 64 patients underwent adrenalectomy for phaeochromocytomas: 21 patients had RA, 38 underwent LA, and 5 underwent OA. The cohort included both men and women, with a median age of 48.2 years. The demographic distribution between the surgical approaches is summarised in Table 1.

Table 1: Patient Demographics

Variable	Laparoscopic (n = 37)	Open (n = 7)	Robotic (n = 20)	Total (n = 64)
Age (years)	52.6 ± 17.1	55.0 ± 12.7	60.9 ± 14.4	55.4 ± 16.1
BMI (kg/m²)	28.3 ± 4.8	31.5 ± 3.9	26.7 ± 3.2	28.1 ± 4.4
Gender				
Male (%)	18 (48.6%)	5 (71.4%)	2 (10.0%)	25 (39.1%)
Female (%)	19 (51.4%)	2 (28.6%)	18 (90.0%)	39 (60.9%)
ASA Score (%)				
ASA 2	10 (38.5%)	1 (14.3%)	2 (10.0%)	13 (24.5%)
ASA 3	15 (57.7%)	6 (85.7%)	16 (80.0%)	37 (69.8%)
ASA 4	1 (3.8%)	0 (0.0%)	2 (10.0%)	3 (5.7%)
Side of Adrenalectomy				
Right (%)	19 (51.4%)	3 (42.9%)	11 (55.0%)	33 (51.6%)
Left (%)	18 (48.6%)	4 (57.1%)	9 (45.0%)	31 (48.4%)
Tumour Size (mm)	43.6	43.7	44.2	

Intraoperative MAP Stability

The mean difference in intraoperative mean arterial pressure was greatest in LA (50.68), followed by RA (40.28), and OA (37.90), however, intraoperative mean arterial pressure did not show any statistically significant differences among the groups. Pairwise comparisons revealed that the differences in MAP between the groups (LA vs OA, LA vs RA, and OA vs RA) did not reach statistical significance under both LSD (p-values: 0.111, 0.064, and 0.771, respectively) and Bonferroni correction (p-values: 0.333, 0.193, and 1.000, respectively). This difference in MAP may reflect improved intraoperative haemodynamic stability, potentially reducing the requirement for vasopressor support.

Inotropic Requirement

There was no statistically significant association between the need for inotropic support and the type of adrenalectomy technique. The Chi-Square test indicated a p-value of 0.154, and further tests confirmed that the choice of surgical technique did not affect the need for inotropic support.

Operating Time

The median operating time for robotic adrenalectomy (RA) was significantly shorter compared to both laparoscopic adrenalectomy (LA) and open adrenalectomy (OA), with RA averaging 61.30 ± 31.37 minutes, LA 104.19 ± 35.98 minutes, and OA 187.86 ± 101.97 minutes ($p < 0.001$). The results of the one-way ANOVA confirmed that these differences were statistically significant ($F = 20.177$, $p = 0.000$), indicating that the choice of surgical technique significantly influenced the duration of the procedure.

Conversation rate and length of stay

The conversion to open rate for RA was 5% compared to 3% for LA. The median length of stay for each surgical approach was LA 3.67 ± 3.64 days, OA 8.80 ± 3.56 days, and RA 1.81 ± 1.03 days. These results indicate that RA had the shortest LOS, followed by LA, with OA having the longest stay. ANOVA revealed a statistically significant difference in LOS between the three approaches ($p<0.05$).

Complication Rates

Complications were classified using the Clavien Dindo system. In the LA group, 34 patients had no complications, while 3 experienced complications greater than Clavien Dindo 3 (CD>3). In the OA group, 4 patients had no complications, and 3 had complications. In the RA group, 19 patients had no complications, while 1 patient had a complication (CD >3). The Chi-Square test showed a significant difference (Pearson = 8.349, df = 2, p = 0.015), with RA demonstrating the lowest complication rate (5%), followed by LA (8%), and OA (43%).

Transfusion Requirements

Transfusion requirements were significantly different among the groups. In the LA group, 25 patients did not require transfusion, and 1 required transfusion. In the OA group, 3 patients did not require transfusion, while 2 required transfusion. No patients in the RA group required transfusion. The Chi-Square test revealed a statistically significant difference (Pearson = 14.651, df = 2, p = 0.001), with OA showing the highest transfusion rate (40%), followed by LA (2.6%), and RA (0%).

Table 2: Intraoperative and postoperative outcomes among patients undergoing robotic-assisted (RA), laparoscopic-assisted (LA), and open approach (OA) procedures.

Outcome	RA (n=21)	LA (n=38)	OA (n=5)
Mean Arterial Pressure	50.7 ± 18.1	37.9 ± 18.5	40.3 ± 19.0
Inotropic Requirement	9 (42.9%)	16 (42.1%)	6 (100%)
Intraoperative BP > 180 mmHg	2 (9.5%)	6 (15.8%)	1 (20%)
Operating Time (mins)	104.2 ± 36.0	187.9 ± 102.	61.3 ± 31.6
Length of Hospital Stay	3.2 ± 4.1 days	3.1 ± 4.5 days	5.6 ± 6.7 days
Complication Rate	1 (5%)	3 (8%)	3 (60%)
Transfusion Requirement	0 (0%)	1 (2.6%)	2 (40%)

Discussion

This study provides insights from a large cohort in the United Kingdom, detailing the outcomes of patients who underwent surgery for phaeochromocytoma (summarised in Table 2). These results demonstrate that RA is associated with significantly lower complication rates, shorter operating time and a shorter mean length of stay than LA and OA. No patients in the RA group required transfusions. It is important to note that the RA group had the lowest BMI, while the OA group had the highest. In our cohort, open surgery was performed for patients with elevated BMI prior to the implementation of the robotic program (pre-2022). After the introduction of the Da Vinci system, patients with higher BMI were offered robotic adrenalectomy, reflecting the value of the robotic platform in facilitating a minimally invasive approach for this patient group. The initial selection of lower BMI patients for RA likely reflects the learning curve phase, and after acquisition of proficiency, the inclusion criteria broadened to include patients with higher BMI.

The comparison between RA and LA for phaeochromocytomas demonstrates several advantages of the robotic approach while also revealing areas where both approaches have comparable outcomes. Furthermore, the conversion rates to open surgery were low across all methods, with RA showing a conversion rate of 5% and LA 3% demonstrating that the minimally invasive techniques are similarly effective in terms of feasibility. Conversion in the RA group was required due to local invasion of the tumour into the renal vein, whereas conversion in the LA group was necessary due to bleeding.

Our study is consistent with published studies that suggest that RA is associated with shorter hospital stays compared to LA. Gan et al.'s systematic review and meta-analysis indicated that RA resulted in significantly less blood loss, a lower conversion rate to open surgery, and a reduced length of hospital stay when compared to LA, with comparable outcomes in terms of complications and readmissions[7]. Similar findings were echoed by Isiktas et al., who also reported less blood loss, shorter hospital stays, and a lower conversion rate for tumours larger than 5 cm in the robotic group[8]. Additionally, Xia et al.'s meta-analysis supports these results, showing that RA is associated with a shorter length of stay, with no significant differences in operating times, transfusion rates, or complication rates compared to LA[9].

However, there is some variability in the findings regarding operating times. While Ma et al.'s randomised controlled trial reported a shorter median operating time for RA[10], Du et al.'s meta-analysis did not find a statistically significant difference in operating times between RA and LA[4]. Moreover, Fu et al. also found no difference in operating times, although RA was associated with lower haemodynamic instability and less intraoperative blood loss[5]. This inconsistency suggests that factors such as tumour size, surgical complexity, and the experience of the surgical team may influence operating time outcomes.

Furthermore, there are mixed results regarding complication rates and other perioperative outcomes. For example, Fang et al. found that both minimally invasive approaches (RA and LA) had similar complication rates, length of hospitalisation, and blood loss[11]. Similarly, Brandao et al. found no significant differences in malignant histology or positive margin rates between the two approaches[12]. These findings suggest that while RA may offer some perioperative advantages, the overall safety profile of both approaches remains largely comparable.

On the other hand, some studies highlight specific contexts where LA may be more favourable. For example, Kim et al. demonstrated that for adrenal tumours ≤5.5 cm, the operation time was shorter for LA compared to RA[13]. However, for tumours larger than 5.5 cm, there was no significant difference in operating times between the two approaches, indicating that tumour size is a critical factor in determining the choice of surgical approach.

RA is also associated with higher hospitalisation costs, as reported by Ma et al.[10]. This factor may influence the decision-making process, particularly in healthcare settings where cost considerations are paramount. A meta-analysis showed that the average total cost of robotic procedures was significantly higher than that

of laparoscopic surgeries, with mean costs of USD 8,695.45 for RA and USD 4,560.20 for LA, respectively[6]. One key factor driving these higher hospitalisation costs is the substantial initial and ongoing investment required for robotic systems. Hospitals face high expenses not only when purchasing or leasing the robotic platform itself, but also when securing maintenance contracts and replacement instruments which often have a limited number of uses before they must be renewed. Despite this, strategic cost-reduction measures and utilisation of an experienced surgical team can reduce the cost difference between RA and LA[14].

While the shorter hospital stay and lower complication rates seen with RA can help offset some expenses by reducing overall resource use (for example, fewer transfusions and potentially faster recovery times), whether these savings fully balance or exceed the initial capital outlay needs to be further investigated in our study.

A limitation of this study is the relatively small sample size. Expanding the cohort or extending the study period would enhance statistical power. Prospective data collection would help standardise patient populations and minimise bias. The selection of surgical approach was based on individual surgeon preference and preoperative clinical judgement in a non-randomised, retrospective setting. This introduces inherent selection bias and likely accounts for much of the variation observed between groups. The OA group primarily consisted of more complex cases, which may introduce a bias in the comparison between the surgical techniques. The higher complication rates and longer operating times observed in the OA group could be influenced by the increased complexity of these cases rather than solely by the surgical approach. While there were no readmissions in the RA group, readmission data were not available for the laparoscopic or open groups. Availability of this data would have been helpful to complement the observed reduction in length of stay following robotic surgery.

These findings support robotic adrenalectomy as a safe and effective option for phaeochromocytoma, particularly in centres with established minimally invasive expertise. Our findings and the literature support the potential of RA as an effective option for adrenalectomy in phaeochromocytoma. Further research is needed to better define the specific contexts and patient populations that would derive the most benefit from robotic surgery.

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References

1. Tsuru N, Suzuki K. (2005) Laparoscopic adrenalectomy. *J Minim Access Surg* 1:165-72. 10.4103/0972-9941.19263

2. Aliyev S, Karabulut K, Agcaoglu O, Wolf K, Mitchell J, Siperstein A, Berber E. (2013) Robotic versus laparoscopic adrenalectomy for phaeochromocytoma. *Ann Surg Oncol* 20:4190-4. 10.1245/s10434-013-3134-z

3. Parente A, Verhoeff K, Wang Y, Wang N, Wang Z, Sledzinski M, et al. (2024) Robotic and Laparoscopic Adrenalectomy for Phaeochromocytoma: An International Multicenter Study. *Eur Urol Focus*. 10.1016/j.euf.2024.09.001

4. Du L, Yang Z, Qi J, Wang Y. (2022) Robotic adrenalectomy versus laparoscopic adrenalectomy for phaeochromocytoma: a systematic review and meta-analysis. *Wideochir Inne Tech Maloinwazyjne* 17:1-8. 10.5114/wiitm.2021.107764

5. Fu SQ, Zhuang CS, Yang XR, Xie WJ, Gong BB, Liu YF, et al. (2020) Comparison of robot-assisted retroperitoneal laparoscopic adrenalectomy versus retroperitoneal laparoscopic adrenalectomy for large phaeochromocytoma: a single-centre retrospective study. *BMC Surg* 20:227. 10.1186/s12893-020-00895-5

6. Esposito G, Mullineris B, Colli G, Curia S, Piccoli M. (2025) Robotic Versus Laparoscopic Adrenalectomy for Adrenal Tumors: An Up-to-Date Meta-Analysis on Perioperative Outcomes. *Cancers (Basel)* 17. 10.3390/cancers17010150

7. Gan L, Peng L, Li J, Meng C, Li K, Wu J, et al. (2022) Comparison of the effectiveness and safety of robotic-assisted and laparoscopic in adrenalectomy: A systematic review and meta-analysis. *Int J Surg* 105:106853. 10.1016/j.ijsu.2022.106853

8. Isiktas G, Nazli Avci S, Ergun O, Krishnamurthy V, Jin J, Siperstein A, Berber E. (2022) Laparoscopic versus robotic adrenalectomy in phaeochromocytoma patients. *J Surg Oncol* 126:460-4. 10.1002/jso.26918

9. Xia Z, Li J, Peng L, Yang X, Xu Y, Li X, et al. (2021) Comparison of Perioperative Outcomes of Robotic-Assisted vs Laparoscopic Adrenalectomy for Phaeochromocytoma: A Meta-Analysis. *Front Oncol* 11:724287. 10.3389/fonc.2021.724287

10. Ma W, Mao Y, Zhuo R, Dai J, Fang C, Wang C, et al. (2020) Surgical outcomes of a randomized controlled trial compared robotic versus laparoscopic adrenalectomy for phaeochromocytoma. *Eur J Surg Oncol* 46:1843-7. 10.1016/j.ejso.2020.04.001

11. Fang AM, Rosen J, Saidian A, Bae S, Tanno FY, Chambo JL, et al. (2020) Perioperative outcomes of laparoscopic, robotic, and open approaches to phaeochromocytoma. *J Robot Surg* 14:849-54. 10.1007/s11701-020-01056-9

12. Brandao LF, Autorino R, Zargar H, Krishnan J, Laydner H, Akca O, et al. (2014) Robot-assisted laparoscopic adrenalectomy: step-by-step technique and comparative outcomes. *Eur Urol* 66:898-905. 10.1016/j.eururo.2014.04.003

13. Kim WW, Lee YM, Chung KW, Hong SJ, Sung TY. (2019) Comparison of Robotic Posterior Retroperitoneal Adrenalectomy over Laparoscopic Posterior Retroperitoneal Adrenalectomy: A Single Tertiary Center Experience. *Int J Endocrinol* 2019:9012910. 10.1155/2019/9012910

14. Feng Z, Feng MP, Feng DP, Rice MJ, Solorzano CC. (2018) A cost-conscious approach to robotic adrenalectomy. *J Robot Surg* 12:607-11. 10.1007/s11701-018-0782-9