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Anatomical four-plane retroperitoneal laparoscopic adrenalectomy for selected unilateral adrenal tumors smaller than 6 cm: technical description and in-hospital outcomes from a single-center retrospective case series

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Abstract

Background

Exposure during retroperitoneal laparoscopic adrenalectomy (RLA) can be limited by a confined working space, adherent perinephric fat, and loss of orientation after peritoneal breach. We developed a standardized four-plane technique using the renal capsule and renal fascia as sequential landmarks. This study describes the operative sequence and reports technical completion and in-hospital outcomes.

Methods

This single-center retrospective case series included 102 patients with selected unilateral adrenal tumors smaller than 6 cm who underwent four-plane RLA at Kaifeng Central Hospital between January 2018 and December 2024. Four surgically defined relatively avascular interfaces were developed after opening the lateroconal fascia. The primary endpoint was completion of the planned four-plane exposure and intended laparoscopic adrenalectomy without open conversion. Secondary endpoints included major injury, intraoperative adverse events, operative time, estimated blood loss, in-hospital postoperative complications, and recovery variables. Outcomes were summarized descriptively, with exact 95% confidence intervals for selected proportions.

Results

All 102 procedures were completed laparoscopically (100%; 95% CI, 96.4–100), with no open conversion or major visceral or vascular injury (each 0%; 95% CI, 0–3.6). Mean operative time was 48.3 ± 6.5 min and mean estimated blood loss was 10.8 ± 5.4 mL. Six intraoperative adverse events occurred: two peritoneal breaches and four superficial renal capsule lacerations; all were managed laparoscopically. Eight patients developed mild postoperative subcutaneous emphysema that resolved without intervention (Clavien–Dindo grade I); no grade II or higher in-hospital postoperative complication was recorded. Median time to oral intake was 12 h and median postoperative hospital stay was 4 days. Follow-up was available for 97 patients; no recurrence was documented over a median 24 months, although surveillance was not uniform.

Conclusions

In this selected single-center cohort, the anatomical four-plane technique achieved complete laparoscopic exposure and adrenalectomy without open conversion. These uncontrolled findings support technical feasibility and describe the in-hospital safety profile, but do not establish superiority over conventional RLA. Prospective comparative studies are required to define optimal indications, learning curve, and reproducibility.

Trial registration:

Not applicable.

Background

Since Gagner et al. first described laparoscopic adrenalectomy in 1992 [1], minimally invasive adrenalectomy has become a standard operative option for many benign adrenal tumors and selected functional lesions [2, 3]. The two most frequently used minimally invasive routes are transperitoneal laparoscopic adrenalectomy (TLA) and retroperitoneal laparoscopic adrenalectomy (RLA). TLA provides a broad operative field and familiar intraperitoneal landmarks, whereas RLA offers direct access to the adrenal region without routine mobilization of intraperitoneal organs [4].

Selection of the operative route depends on tumor size, laterality, endocrine function, radiologic suspicion of malignancy, body habitus, previous surgery, and surgeon experience. RLA is well suited to selected unilateral tumors of small-to-moderate size, but its technical advantages depend on maintaining orientation in a narrow, fat-filled space. Thick or adherent perinephric fat can obscure the renal upper pole and adrenal margins. The gland may be difficult to distinguish from surrounding fat, particularly when normal adrenal tissue is small or distorted by a tumor. In addition, inadvertent peritoneal breach may reduce the effective retroperitoneal space and alter familiar visual cues. These factors can lead to repeated tissue manipulation and loss of a stable dissection sequence around the renal upper pole, diaphragm, peritoneal reflection, and adrenal pedicle.

Zhang et al. described anatomical retroperitoneoscopic adrenalectomy based on standardized dissection through three relatively avascular planes, providing a reproducible strategy for adrenal exposure [5]. Later modifications, including single-layer and extra- or intraperinephric fat approaches, have altered the route or sequence of exposure to adapt the procedure to different anatomical conditions [6, 7]. These developments support a broader principle: during RLA, reproducible tissue interfaces and stable landmarks may be more useful than nonselective clearance of retroperitoneal fat.

Based on our previous modification experience [8], we developed a standardized anatomical four-plane technique. The approach first establishes a renal capsular reference plane and then sequentially exposes the anterior, posterior, and renal surfaces of the adrenal gland. The added fourth plane deliberately develops the interface between the adrenal base and the upper renal pole. It is intended as an extension of the three-plane anatomical concept rather than its replacement. The present study describes the operative anatomy and technical sequence and reports technical completion and in-hospital outcomes in a single-center retrospective case series.

Methods

Study design and setting

This single-center retrospective case series was reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations where applicable [9]. Medical records and operative videos of patients with adrenal tumors who underwent anatomical four-plane RLA in the Department of Urology, Kaifeng Central Hospital, between January 2018 and December 2024 were reviewed. The study was approved by the Ethics Committee of Kaifeng Central Hospital (Approval No. 2022ks012). The ethics committee waived the requirement for individual written informed consent for the retrospective analysis of anonymized data. This retrospective observational study was not designed as a prospective interventional trial.

Participants and preoperative evaluation

Eligible patients had a unilateral adrenal tumor smaller than 6 cm and had been selected for laparoscopic surgery under general anesthesia in routine clinical practice. The cohort included clinically suspected functional adrenal tumors and nonfunctioning adrenal masses for which surgery had been recommended after clinical and imaging assessment. Exclusion criteria were bilateral adrenal tumors, adrenal metastases, a history of ipsilateral retroperitoneal surgery or intervention, uncorrected coagulopathy, or another absolute contraindication to laparoscopic surgery.

Preoperative assessment included complete blood count, urinalysis, coagulation testing, serum biochemistry, blood typing, electrocardiography, and chest imaging. Endocrine evaluation was selected according to clinical presentation and included serum cortisol rhythm, adrenocorticotropic hormone (ACTH), assessment of the renin–angiotensin–aldosterone system, plasma catecholamines, 24-h urinary cortisol, and urinary vanillylmandelic acid (VMA) when clinically indicated. Tumor location, maximum diameter, and anatomical relationships were assessed by unenhanced and contrast-enhanced adrenal computed tomography (CT), with magnetic resonance imaging (MRI) when necessary. The risk of adherent perinephric fat was graded on preoperative CT using the Mayo Adhesive Probability (MAP) score [10].

Preoperative preparation

Preoperative management was individualized according to endocrine function. Patients with suspected pheochromocytoma received antihypertensive treatment and preoperative volume expansion according to the treating endocrinology and anesthesia teams. Hypokalemia associated with primary aldosteronism was corrected before surgery. Perioperative glucocorticoid replacement was administered to patients with hypercortisolism when clinically indicated. Diabetes mellitus and cardiovascular or cerebrovascular comorbidities were optimized before surgery.

Anesthesia, position, and retroperitoneal access

All procedures were performed under combined intravenous–inhalational general anesthesia with endotracheal intubation. At least two peripheral venous lines were established, and a central venous catheter was placed in patients with suspected pheochromocytoma. Patients were positioned in a 90° lateral decubitus jackknife position with the affected side upward. Perioperative antimicrobial prophylaxis was administered approximately 30 min before skin incision according to the institutional protocol.

Three ports were placed below the costal margin at the posterior axillary line, at the anterior axillary line, and above the iliac crest, with an interport distance of approximately 8–10 cm. After blunt clearance of extraperitoneal fat, the quadratus lumborum muscle, peritoneal reflection, and lateroconal fascia were identified. The lateroconal fascia was opened longitudinally approximately 1 cm from the quadratus lumborum muscle, extending cranially to the subdiaphragmatic region and caudally to the superior margin of the iliac fossa, thereby exposing the renal fascia.

Four-plane adrenal dissection

The procedure used a standardized sequence of four relatively avascular surgical tissue interfaces around the kidney and adrenal gland (Fig. 1). In this report, the term perinephric fat envelope refers to the adipose tissue surrounding the kidney within the renal fascia. The four planes are defined by reproducible intraoperative boundaries and should be regarded as surgically defined dissection interfaces rather than histologically validated fascial spaces. The term renal surface of the adrenal gland is used as an operative descriptor for the adrenal surface facing the upper renal pole.

First plane—renal capsular plane over the mid-to-upper kidney. At the lateral border of the mid kidney, adjacent to the cranial end of the lateroconal fascial incision, a vertical incision was made through the anterior renal fascia and the full thickness of the perinephric fat. Blunt and sharp dissection was continued medially and cranially through the relatively avascular interface between the renal capsule and perinephric fat until the anterior surface of the upper renal pole was exposed.

Second plane—anterior surface of the adrenal gland. The medial border of the anterior parenchymal surface of the upper renal pole was used as the reference line. The full thickness of the upper-pole perinephric fat was opened obliquely in a cranial direction, and the bluish-white peritoneum was identified. The incision was enlarged, after which curved blunt and sharp dissection was advanced medially, cranially, and deeply through the relatively avascular interface between the perinephric fat and anterior renal fascia. The golden-yellow adrenal gland or adrenal tumor was identified and its anterior surface was exposed.

Third plane—posterior surface of the adrenal gland. Blunt and sharp dissection was performed through the relatively avascular interface between the superolateral perinephric fat and posterior renal fascia, exposing the lumbar fascial surface of the diaphragm. The plane was developed medially to the

posteromedial margin of the upper renal pole, cranially to the diaphragmatic dome, and caudally toward the renal hilum, thereby exposing the posterior surface of the adrenal gland.

Fourth plane—renal surface of the adrenal gland. Near the diaphragm, the superolateral fat over the upper renal pole was incised vertically in an inferomedial direction. Guided by the lateral border of the previously exposed anterior adrenal surface, dissection entered the relatively avascular interface between the renal parenchyma of the upper pole and the fat at the adrenal base. Blunt and sharp dissection was continued along the renal capsule to expose the renal surface of the adrenal gland and was terminated at the anteromedial margin of the upper renal pole.

After completion of the four planes, the renal capsular surface over the mid-to-upper kidney and the anterior, posterior, and renal surfaces of the adrenal gland were exposed. Gravity displaced the upper kidney posteroinferiorly, while retroperitoneal insufflation elevated the anterior perinephric fat and peritoneum. This altered the local configuration of the superomedial retroperitoneal space and reduced tissue obstruction around the adrenal gland.

Total or partial adrenalectomy

After the four planes had been developed, the adrenal gland was mobilized sufficiently to permit total or partial adrenalectomy according to the clinical indication and tumor location. The inferomedial border was dissected carefully. The inferior and middle adrenal arterial branches and the central adrenal vein were isolated in small bundles, clipped, and divided. The superior adrenal pedicle was managed subsequently, and the specimen was retrieved in a protective bag. For partial adrenalectomy, the lesion was excised along the tumor margin while preserving viable adrenal parenchyma when feasible. Before closure, retroperitoneal insufflation pressure was reduced and the operative bed was inspected for bleeding. A retroperitoneal drain was placed routinely.

Postoperative management and follow-up

Postoperative monitoring included pulse oximetry, electrocardiography, and blood pressure measurement. Fluid and electrolyte balance was maintained, and glucocorticoids were administered when clinically indicated. The urinary catheter was removed on postoperative day 1, early mobilization was encouraged, and oral intake was initiated as recovery permitted. The retroperitoneal drain was removed when daily output was less than 20 mL and there was no clinical or imaging evidence of a clinically significant retroperitoneal collection.

Follow-up was conducted through outpatient visits or telephone contact. Available information included symptoms, medication use for functional tumors, biochemical results, imaging findings, and documented recurrence. Perioperative safety outcomes were defined from the index hospitalization. Postdischarge records were reviewed when available for readmission, reintervention, and delayed

adverse events; however, 30-day and 90-day event ascertainment was not standardized prospectively and was therefore not used as a formal endpoint.

Outcomes and statistical analysis

The primary endpoint was technical completion of the planned four-plane exposure and intended laparoscopic adrenalectomy without conversion to open surgery. Secondary endpoints included conversion, major visceral or vascular injury, operative time, estimated blood loss (EBL), transfusion, intraoperative adverse events, postoperative complications during the index hospitalization, drainage duration, time to oral intake, postoperative hospital stay, available endocrine recovery indicators, and documented recurrence. EBL was abstracted from the operative and anesthesia records as the documented intraoperative estimate. Major visceral or vascular injury was operationally defined as injury to a major vessel or hollow or solid viscus that required major repair, unplanned organ resection, transfusion, conversion, or resulted in postoperative organ dysfunction. Intraoperative adverse events were described separately and were not assigned Clavien–Dindo grades. Postoperative complications were graded according to the Clavien–Dindo classification [11].

Statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Continuous variables with an approximately normal distribution are presented as mean ± standard deviation (SD); skewed variables are presented as median (range). Categorical variables are presented as number and percentage. Exact two-sided 95% confidence intervals (CIs) based on the binomial distribution were calculated for technical completion, conversion, and major visceral or vascular injury. No formal power calculation or comparative hypothesis testing was performed because this was a single-arm descriptive case series. Perioperative analyses included all eligible patients who underwent four-plane RLA; follow-up outcomes were analyzed among patients with available follow-up data.

Results

Patient and tumor characteristics

A total of 102 patients with adrenal tumors were included. There were 43 males and 59 females, and the median age was 45 (range, 32–74) years. The median body mass index was 25.4 (range, 18.9–35.1) kg/m². Forty-five patients presented with hypertension, 14 with hypokalemia, and 5 with clinical features suggestive of hypercortisolism. Seven patients had undergone previous abdominal surgery. Comorbidities included diabetes mellitus in 11 patients, coronary artery disease in 10, and remote cerebral infarction in 5.

Tumors were left-sided in 60 patients and right-sided in 42. Median maximum tumor diameter was 2.7 (range, 1.1–5.8) cm. Median MAP score was 2 (range, 0–5); 82 patients had a MAP score of 0–2 and 20 had a score of 3–5. Preoperative clinical diagnostic categories were unilateral primary aldosteronism in

15 patients, pheochromocytoma in 21, cortisol-producing adrenal adenoma in 14, nonfunctioning adrenal adenoma in 40, myelolipoma in 8, and adrenal cyst in 4 (Table 1).

Table 1
Baseline patient and tumor characteristics and preoperative clinical diagnostic categories.

Characteristic	Value
Total patients	102
Sex, male/female	43 (42.2)/59 (57.8)
Age, years	45 (32–74)
Body mass index, kg/m²	25.4 (18.9–35.1)
Hypertension	45 (44.1)
Hypokalemia	14 (13.7)
Clinical features suggestive of hypercortisolism	5 (4.9)
Previous abdominal surgery	7 (6.9)
Diabetes mellitus	11 (10.8)
Coronary artery disease	10 (9.8)
Remote cerebral infarction	5 (4.9)
Tumor side, left/right	60 (58.8)/42 (41.2)
Maximum tumor diameter, cm	2.7 (1.1–5.8)
MAP score	2 (0–5)
MAP score 0–2	82 (80.4)
MAP score 3–5	20 (19.6)
Unilateral primary aldosteronism	15 (14.7)
Pheochromocytoma	21 (20.6)
Cortisol-producing adrenal adenoma	14 (13.7)
Nonfunctioning adrenal adenoma	40 (39.2)
Myelolipoma	8 (7.8)
Adrenal cyst	4 (3.9)

Values are n (%) or median (range), unless otherwise indicated. MAP, Mayo Adhesive Probability.

Operative and in-hospital outcomes

The planned four-plane exposure and intended laparoscopic adrenalectomy were completed in all 102 patients (100%; exact 95% CI, 96.4–100). No patient required conversion to open surgery and no major visceral or vascular injury occurred (each 0%; exact 95% CI, 0–3.6). Mean operative time was 48.3 ± 6.5 min and mean EBL was 10.8 ± 5.4 mL (range, 5–60 mL). No perioperative blood transfusion was required (Table 2).

Marked adherent perinephric fat was documented intraoperatively in four male patients, all with a preoperative MAP score of 5. In these patients, the first plane was more difficult to develop and the capsular dissection sequence was modified according to the locally identifiable tissue interface.

Six intraoperative adverse events occurred: two peritoneal breaches and four superficial renal capsule lacerations. The peritoneal breaches occurred during second-plane dissection. After decompression of the intraperitoneal gas, an auxiliary 5-mm trocar was used to maintain exposure and both operations were completed laparoscopically. The superficial renal capsule lacerations were managed with bipolar coagulation. Eight patients developed mild postoperative subcutaneous emphysema that resolved spontaneously within 1–2 days without additional intervention and was classified as Clavien–Dindo grade I. No grade II or higher postoperative complication was recorded during the index hospitalization.

Median drainage duration was 27 (range, 22–35) h, median time to oral intake was 12 (range, 6–24) h, and median postoperative hospital stay was 4 (range, 2–7) days. No wound infection, acute intestinal obstruction, hypertensive crisis, or acute adrenocortical insufficiency was documented during the index hospitalization. Final pathological categories were concordant with the broad preoperative diagnostic groups.

Table 2
In-hospital perioperative and available functional and follow-up outcomes.

Outcome	Value
Technical completion of planned four-plane RLA	102 (100; 95% CI, 96.4–100)
Conversion to open surgery	0 (0; 95% CI, 0–3.6)
Major visceral or vascular injury	0 (0; 95% CI, 0–3.6)
Operative time, min	48.3 ± 6.5
Estimated blood loss, mL	10.8 ± 5.4; range, 5–60
Perioperative blood transfusion	0
Marked adherent perinephric fat	4 (3.9)
Any intraoperative adverse event	6 (5.9)
Peritoneal breach	2 (2.0)
Superficial renal capsule laceration	4 (3.9)
Postoperative Clavien–Dindo grade I complication (mild subcutaneous emphysema)	8 (7.8)
Postoperative Clavien–Dindo grade II or higher complication	0
Drainage duration, h	27 (22–35)
Time to oral intake, h	12 (6–24)
Postoperative hospital stay, days	4 (2–7)
Follow-up information available	97 (95.1)
Lost to follow-up	5 (4.9)
Follow-up duration, months	24 (12–56)
Postoperative oral prednisone replacement duration in cortisol-producing adrenal adenoma, months (n = 14)	4 (3–6)
Postoperative spironolactone required in unilateral primary aldosteronism	0/15
Serum potassium at the lower limit of normal during follow-up in unilateral primary aldosteronism	1/15
Documented recurrence in available records	0/97

Values are n (%), mean ± SD, median (range), or n/N, unless otherwise indicated. CI, confidence interval; RLA, retroperitoneal laparoscopic adrenalectomy; SD, standard deviation.

Available functional and follow-up outcomes

Follow-up information was available for 97 of 102 patients (95.1%); 5 patients were lost to follow-up because of changed contact information or continued care at another institution. Median follow-up duration was 24 (range, 12–56) months. Among 14 patients with cortisol-producing adrenal adenoma, the median duration of postoperative oral prednisone replacement was 4 (range, 3–6) months. None of the 15 patients with unilateral primary aldosteronism required postoperative spironolactone. One patient had serum potassium at the lower limit of normal during follow-up, and a contralateral aldosterone-producing microadenoma could not be excluded. No recurrence was documented in the available records of the 97 followed patients; however, imaging and disease-specific endocrine surveillance were not uniform.

Discussion

This retrospective case series describes a standardized sequential four-plane exposure strategy for RLA in selected unilateral adrenal tumors smaller than 6 cm. The planned exposure and intended laparoscopic adrenalectomy were completed in all patients, with no conversion or major visceral or vascular injury observed during the index operation. These findings support technical feasibility in the hands of an experienced team. Because the study had no comparator and did not standardize postdischarge event capture, the results should not be interpreted as evidence that the technique is safer or more effective than conventional RLA.

The operative rationale is to replace nonselective clearance of retroperitoneal fat with a sequence of surgically defined tissue interfaces. The first plane exposes the renal capsule over the mid-to-upper kidney and provides an early reference landmark. The second plane separates the perinephric fat from the anterior renal fascia and reveals the anterior adrenal surface. The third plane develops the interface between the superolateral perinephric fat and posterior renal fascia, exposing the posterior adrenal surface and the lumbar fascial surface of the diaphragm. The fourth plane follows the renal capsule between the upper renal pole and the fat at the adrenal base, thereby exposing the renal surface of the adrenal gland.

The fourth plane should therefore be interpreted as an extension of, rather than a replacement for, the established three-plane concept described by Zhang et al. [5]. Its intended contribution is completion of renal-surface exposure before definitive pedicle control. Once the upper renal pole and the three surgically defined adrenal surfaces have been exposed, gravity displaces the kidney posteroinferiorly and retroperitoneal insufflation elevates the anterior perinephric fat and peritoneum. This configuration can enlarge the superomedial working space and reduce tissue obstruction. The present series shows that the sequence can be implemented consistently within one experienced surgical team, but it does not provide cadaveric, histological, or independent multicenter validation that these interfaces are constant anatomical fascial planes.

The technique did not eliminate intraoperative adverse events. Two peritoneal breaches occurred during second-plane dissection and required an auxiliary trocar to maintain exposure; four superficial renal capsule lacerations occurred during capsular-plane development. These events underline the importance of identifying the peritoneum and renal capsule before extending a plane. When perinephric fat is adherent, forceful continuation of an indistinct interface may be more harmful than limited sharp dissection or modification of the sequence.

What the technique adds should be interpreted anatomically rather than as a proven clinical advantage. Later modifications of anatomical RLA have attempted to simplify plane development or select different extra- and intraperinephric routes [6, 7, 23]. The four-plane approach instead emphasizes a renal capsular reference and deliberate development of the upper-pole–adrenal interface. This may be useful when perinephric fat obscures the adrenal field or when the renal surface of the adrenal gland is difficult to define. However, the absence of a parallel three-plane control group means that this series cannot determine whether the added plane reduces peritoneal breach, shortens operative time, or lowers blood loss.

Contemporary studies have reported favorable perioperative outcomes after selected laparoscopic and retroperitoneoscopic adrenalectomy, although operative difficulty varies with tumor size, functional status, body habitus, adhesions, and surgeon experience [12–16]. Large adrenalectomy series also show that the type and frequency of complications depend on case mix and the completeness of event ascertainment [17–19]. The operative time and EBL observed in this cohort fall within ranges reported in contemporary series, but cross-study comparisons are inherently limited by differences in patient selection, surgical approach, definition of operative time, and EBL measurement. In particular, EBL in the present study was a retrospective clinical estimate rather than a protocolized gravimetric outcome. The low mean value should therefore be interpreted descriptively rather than as evidence of superiority.

Perinephric fat characteristics appear clinically relevant during RLA. The MAP score was originally developed to predict adherent perinephric fat in partial nephrectomy [10], and more recent adrenalectomy studies have reported associations between adherent perinephric fat scores and operative difficulty [24, 25]. In the present cohort, the four patients with marked adhesions all had a MAP score of 5 and required modification of the initial capsular dissection. This observation is hypothesis-generating rather than a formal MAP subgroup analysis. It suggests that high MAP scores may identify patients in whom the first and fourth planes are more difficult to develop, but the current sample is insufficient to define a threshold or contraindication.

Recovery variables in this series were recorded during routine clinical care. Median time to oral intake was 12 h and median postoperative stay was 4 days. Short-stay and outpatient adrenalectomy pathways have been reported in selected patients [13, 20, 21], but discharge timing is influenced by institutional practice, endocrine diagnosis, monitoring requirements, and local health-care systems. The present recovery data therefore describe the institutional pathway rather than a direct effect of the four-plane dissection sequence.

Standardization is a potential value of anatomical exposure strategies, but it cannot be inferred from a 100% completion rate alone. Reproducibility across surgeons requires explicit landmarks, a teachable sequence, and objective assessment of the learning curve. Staged training has been shown to influence performance in laparoscopic adrenalectomy [22]. In the current study, surgeon workload, NASA Task Load Index scores, ergonomic burden, step-specific operating times, and learning-curve metrics were not prospectively collected. Future studies should combine video-based step assessment with surgeon-reported workload and cumulative performance measures to determine whether the four-plane sequence improves training or reproducibility.

The available follow-up data should also be interpreted cautiously. No recurrence was documented among 97 followed patients, but this cohort consisted predominantly of selected benign or functional adrenal tumors and surveillance was not uniform. Disease-specific endocrine outcomes were not classified using uniform contemporary criteria. For example, primary aldosteronism outcomes were not assessed with a standardized clinical and biochemical success framework, and pheochromocytoma follow-up did not uniformly include biochemical surveillance in the available dataset. These data therefore do not establish definitive long-term endocrine or oncological efficacy.

This study has several limitations. First, its retrospective single-center design introduces selection bias and limits external validity; the cohort represents patients selected for four-plane RLA by an experienced team and does not capture all patients evaluated for alternative operative approaches. Second, the absence of a parallel control group prevents attribution of operative time, blood loss, peritoneal breach, or recovery to the four-plane technique. Third, complications were systematically recorded during the index hospitalization, but 30-day and 90-day complications, readmissions, and reinterventions were not prospectively standardized; delayed low-grade events may therefore have been underdetected. Fourth, surgeon workload, NASA Task Load Index scores, ergonomic burden, learning-curve metrics, and inter-surgeon reproducibility were not assessed. Fifth, MAP scoring was used clinically, but blinded duplicate assessment and interobserver agreement were not available. Sixth, the cohort was heterogeneous with respect to endocrine diagnosis and extent of adrenal resection, and procedure- or diagnosis-specific subgroup analyses were not performed. Seventh, postoperative endocrine and imaging surveillance was not uniform, limiting disease-specific outcome assessment. Finally, the four interfaces described here are surgically defined planes and have not been validated by cadaveric or histological studies.

A prospective comparative design is required to determine whether the anatomical sequence itself changes operative efficiency or safety. Such studies should compare the four-plane approach with conventional three-plane RLA in contemporaneous patients, use standardized definitions for operative time and blood loss, capture 30- and 90-day complications, and prespecify analyses by MAP score and tumor characteristics. Video-based assessment of landmark identification, step completion, and technical deviations, together with surgeon workload and learning-curve measures, would be particularly informative.

Conclusions

In selected patients with unilateral adrenal tumors smaller than 6 cm, the anatomical four-plane RLA sequence was technically completed without conversion in all 102 procedures in this single-center retrospective series. The approach uses the renal capsule and renal fascia as sequential operative landmarks to expose the anterior, posterior, and renal surfaces of the adrenal gland. The observed in-hospital outcomes support technical feasibility and provide a descriptive safety profile in an experienced team. Because the study was uncontrolled, it does not establish that the four-plane technique is superior to conventional RLA. Prospective comparative and video-based studies are needed to define its indications, learning curve, and reproducibility.

List of abbreviations

ACTH, adrenocorticotropic hormone; BMI, body mass index; CI, confidence interval; CT, computed tomography; EBL, estimated blood loss; MAP, Mayo Adhesive Probability; MRI, magnetic resonance imaging; RLA, retroperitoneal laparoscopic adrenalectomy; SD, standard deviation; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology; TLA, transperitoneal laparoscopic adrenalectomy; VMA, vanillylmandelic acid.

Declarations

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Kaifeng Central Hospital (Approval No. 2022ks012). The requirement for individual written informed consent was waived by the ethics committee because of the retrospective design and anonymized data analysis.

Consent for publication

Not applicable. No identifiable individual participant data are presented.

Competing interests

The authors declare that they have no competing interests.

Authors' information

Not applicable.

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Author Contribution

H.Q.: Conceptualization, methodology, investigation, formal analysis, writing—original draft, writing—review and editing. F.Z.: Methodology, investigation, writing—review and editing. S.Y.: Conceptualization, formal analysis, writing—original draft, writing—review and editing. X.R.: Conceptualization, supervision, writing—original draft, writing—review and editing. G.P.: Investigation, writing—review and editing. J.T.: Investigation, writing—review and editing. X.Z.: Investigation, writing—review and editing. H.Q., S.Y., and X.R. are guarantors of the integrity of the study. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available because of the protection of individual patient privacy and restrictions imposed by the Ethics Committee of Kaifeng Central Hospital, but are available from the corresponding author on reasonable request and with permission of the institutional ethics committee.

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Figures

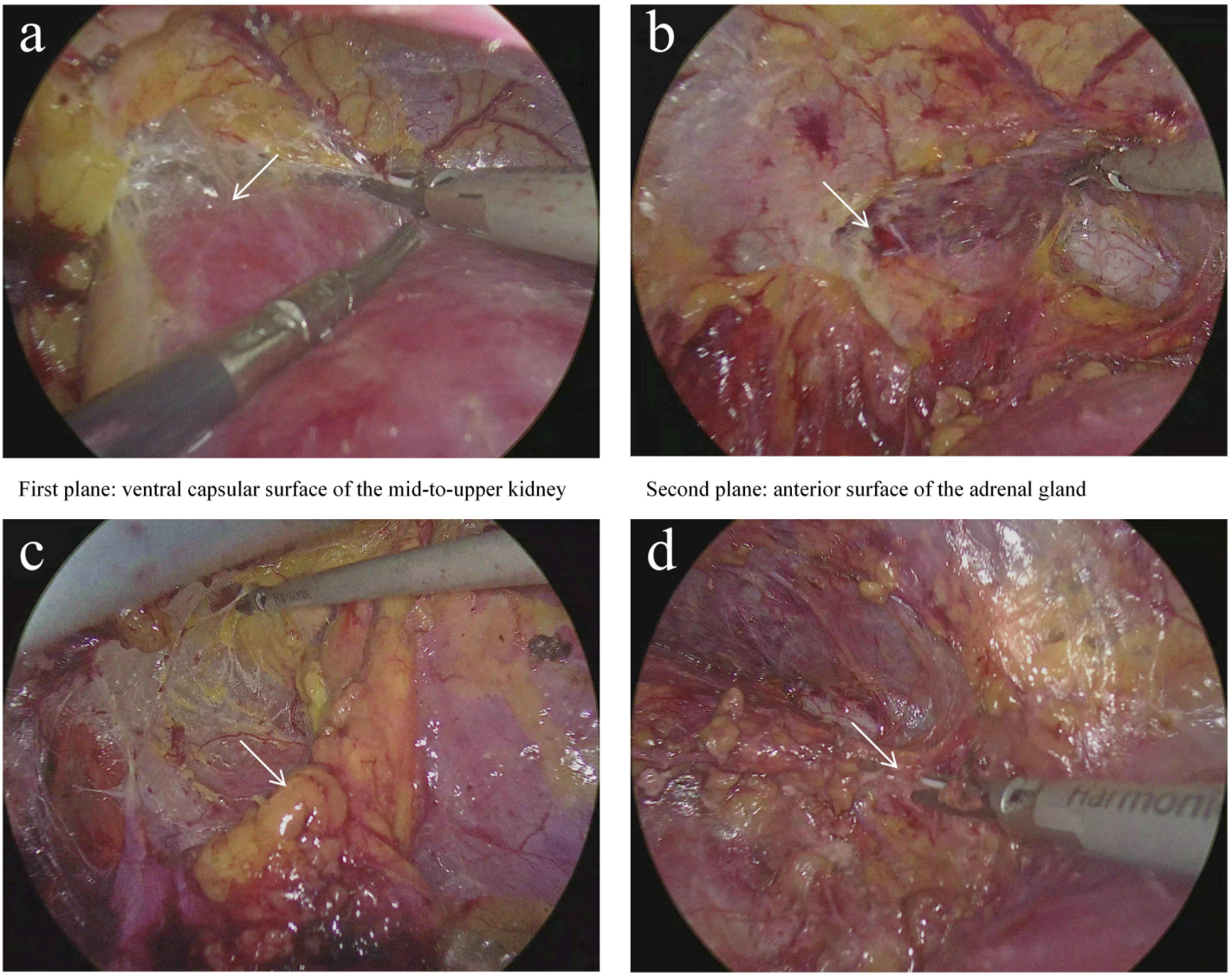


Figure 1

Anatomical four-plane dissection on the right side. Intraoperative images show the four surgically defined dissection interfaces. (a) P1, renal capsular plane over the mid-to-upper kidney: the relatively avascular interface between the renal capsule and perinephric fat is developed medially and cranially. (b) P2, anterior adrenal plane: dissection between the perinephric fat and anterior renal fascia exposes the anterior adrenal surface. (c) P3, posterior adrenal plane: dissection between superolateral perinephric fat and posterior renal fascia exposes the posterior adrenal surface and the lumbar fascial surface of the diaphragm. (d) P4, renal-surface plane: dissection follows the upper-pole renal capsule beneath the adrenal base to expose the renal surface of the adrenal gland.