

Screening criteria for drainage-free patients after retroperitoneal laparoscopic adrenal tumor resection and their prospective validation study value

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Abstract. Retroperitoneal laparoscopic resection is the preferred minimally invasive surgery for adrenal tumors. Patients vary greatly in postoperative drain output, but no clear criteria exist to select candidates for a drainage-free strategy. The objective of the present study was to establish clinical screening criteria for identifying patients eligible for a drainage-free strategy after retroperitoneal laparoscopic adrenal tumor resection and verify the clinical value of the criteria. A retrospective analysis was first conducted on 126 patients who underwent the aforementioned surgery. Patients were divided into two groups based on total postoperative drain output: The drainage-free group (≤ 60 ml, 40 cases) and the drain group (>60 ml, 86 cases). Indicators such as age and tumor diameter were compared with identify factors influencing postoperative drain output. Subsequently, a prospective validation study was carried out involving 54 patients, with 20 patients meeting the preliminary screening criteria assigned to the experimental group and 34 ineligible patients to the control group. Perioperative data and complication rates of the two groups were compared. The

retrospective univariate analysis identified seven indicators (including age and tumor diameter) associated with postoperative drain output ($P < 0.05$). Multivariate logistic regression confirmed five independent risk factors for postoperative drain output: Age [odds ratio (OR)=1.062; 95% confidence interval (CI) 1.005-1.123; $P=0.033$], tumor diameter (OR=2.199; 95% CI: 1.162-4.159; $P=0.015$), locking clip application for adrenal tissue or central vein (OR=12.081; 95% CI: 1.772-82.385; $P=0.011$), saponification and adhesion of adipose tissue in the surgical area (OR=0.092; 95% CI: 0.026-0.319; $P < 0.001$) and intraoperative blood loss (OR=10.48; 95% CI: 1.025-1.072; $P < 0.001$). In the prospective validation study, only one patient in the experimental group had postoperative drain output >60 ml (recovered with conservative treatment). The experimental group also had significantly less total drain output, shorter drain removal time and shorter hospital discharge time than the control group ($P < 0.05$), with no significant difference in complication rates ($P > 0.05$). In conclusion, the established screening criteria may accurately identify eligible patients. This strategy appears to safely shorten hospital stays and facilitate stratified management and may have clinical value.

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Introduction

Adrenal tumors are relatively common in adults, and can originate from the adrenal cortex, medulla or adjacent tissue structures, including adrenocortical carcinoma, non-functional adenoma, lymphoma, paraganglioma and pheochromocytoma. However, in the pediatric population, adrenal malignancies are rare and heterogeneous, mainly comprising neuroblastoma, ganglioneuroblastoma, adrenocortical carcinoma and malignant pheochromocytoma. Neuroblastoma alone accounts for nearly 10% of all childhood cancers, with ~35% arising from the adrenal medulla. These tumors are often aggressive and are frequently diagnosed at an advanced stage with local invasion or distant metastasis (1-3). Traditionally, open surgical resection was the main treatment, but it involves large incisions, long recovery and marked complication risk. With the evolution

of surgical techniques, minimally invasive procedures have been widely adopted owing to advantages including less tissue trauma, faster postoperative recovery, shorter hospital stay, lower perioperative morbidity and other related benefits (4). In recent years, with minimally invasive advances, laparoscopic surgery has become the preferred treatment for adult adrenal tumors (5); robot-assisted laparoscopic adrenalectomy, a specialized minimally invasive approach, is also used clinically (6,7). Compared with transabdominal laparoscopy, retroperitoneal laparoscopy reduces intraoperative injury to the intestines/liver and postoperative complications; therefore, more centers now use it as the preferred approach for adrenal tumor resection (8,9). Despite its clinical value, early data show some patients need reoperation due to bleeding after laparoscopic adrenal tumor resection, prompting clinical exploration of strategies to reduce postoperative bleeding and drain output (10).

In clinical practice, patients undergoing retroperitoneal laparoscopic adrenal tumor resection have notable individual differences in postoperative drain output; some patients have a relatively large output, while others have almost none. Stratifying patients by postoperative drain output characteristics and applying individualized diagnosis and treatment can optimize medical resource allocation and accelerate patient recovery. Against this background, the present study first explored factors influencing drain output after the surgery via retrospective analysis; then formulated clinical screening criteria for patients with no postoperative drain output; and finally verified these criteria through a prospective study. Specifically, the present research aimed to provide a reliable evidence-based foundation for making precise, postoperative drain output-related patient management decisions in clinical practice, such as determining whether to place or remove a drain or optimizing drain management strategies.

Materials and methods

Inclusion and exclusion criteria. Inclusion criteria for the retrospective study: i) Patients who underwent retroperitoneal laparoscopic adrenal tumor resection; and ii) aged >18 years. Exclusion criteria for the retrospective study: i) Abnormal coagulation function; ii) cardiopulmonary dysfunction, severe hepatic or renal insufficiency or other comorbidities that render patients unable to tolerate surgery; iii) total adrenalectomy; iv) prolonged operation time due to specific instrument failures (damage to energy devices such as ultrasonic scalpels, breakdown of camera systems or light sources confirmed by intraoperative inspection) or other unavoidable intraoperative reasons; v) adrenal cysts; vi) adrenal hemangiomas; and vii) Conversion to open surgery or other surgical methods. The inclusion criteria and exclusion criteria for the prospective study were the same as those for the retrospective study.

Study population and grouping in the retrospective study. A retrospective analysis was conducted on 126 patients who underwent retroperitoneal laparoscopic adrenal tumor resection at Xuzhou Cancer Hospital (Xuzhou, China) from March 2023 to April 2025. All data were collected from electronic and paper medical records. All patients completed preoperative hormone tests and had electrolytes adjusted to normal;

those with pheochromocytoma received routine preoperative volume expansion therapy to stabilize blood pressure. All 126 patients underwent the surgery successfully. Their basic data were collected, including sex, age, BMI, comorbidities, postoperative pathology, tumor size and perioperative indicators (details in Table I). Since no established criteria or relevant guidelines exist, 60 ml was selected as the cut-off in the present study based on empirical evidence and physiological rationale. As some drain output inevitably remains postoperatively, zero drainage is unrealistic. We hypothesized that drain output ≤ 60 ml could be completely absorbed without adverse events. Patients were stratified into a drainage group (>60 ml) and a drainage-free group (≤ 60 ml). Univariate and multivariate logistic regression analyses were used to compare the two groups, identify factors influencing postoperative drain output and establish screening criteria for drainage-free patients.

Study population and grouping in the prospective validation study based on screening criteria. A further prospective validation analysis included 54 patients who underwent retroperitoneal laparoscopic adrenal tumor resection at Xuzhou Cancer Hospital and the Affiliated Huai'an No. 1 People's Hospital of Nanjing Medical University (Huai'an, China) from April to August 2025. Data were collected prospectively during perioperative inpatient visits and follow-ups. Among them, 20 patients meeting the preliminary screening criteria derived from our retrospective analysis for non-postoperative drain output were in the experimental group, and 34 patients who did not meet these criteria were in the control group. Sample size calculation was performed using G*Power 3.1 software (Heinrich Heine University Düsseldorf, Germany). With an effect size set at 0.8, the current sample size achieved a statistical power of 0.8. All patients completed preoperative hormone tests and had electrolytes adjusted to normal; those with pheochromocytoma received routine preoperative volume expansion therapy to stabilize blood pressure. The present study followed The Declaration of Helsinki and was approved by the Ethics Committees of Xuzhou Cancer Hospital (Xuzhou, China; approval no. 2025-CS-011) and the Affiliated Huai'an No. 1 People's Hospital of Nanjing Medical University (Huai'an, China; approval no. 2025-008). For the prospective cohort, informed consent was obtained from all patients or their legal representatives, with such representation used only for a small number of patients with limited decision-making capacity. For the retrospective cohort, individual informed consent was not required for this observational study using existing medical records.

Surgical steps. Surgical methods were consistent across retrospective and prospective cohorts. All procedures were retroperitoneal with patients in the contralateral lateral decubitus position. A total of three trocars were placed: 10-mm at 2 transverse fingers above iliac spine (midaxillary line), 5-mm below costal margin (anterior axillary line) and 12-mm below costal margin (posterior axillary line). After pneumoperitoneum establishment, ultrasonic scalpel dissected perirenal fascial adipose tissue, incised fascia and separated the perirenal fascia from the fat capsule. Dissection started dorsally toward the upper renal pole to expose tumor, then continued ventrally along peritoneum to clarify boundaries. Surrounding

Table I. General data of patients in retrospective study.

Variable	Number (n)/value
Sex	
Male	67
Female	59
Age, years	52.3±11.6
BMI, kg/m ²	25.5±3.5
Pathology	
Non-functional adenoma	80
Myelolipoma	6
Pheochromocytoma	8
Aldosteronoma	25
Nodular hyperplasia	4
Ganglioneuroma	3
Tumor location	
Left side	74
Right side	52
Total drain output volume, ml	120.7±95.7
Complicated with hypertension	
Yes	77
No	49
Complicated with diabetes mellitus	
Yes	16
No	110
Long-term use of anticoagulants	
Yes	15
No	111
Operation duration, min	81.6 (60.0-100.0)
Tumor diameter, cm	2.6 (1.8-3.0)
Use of anticoagulants within 12 h after operation	
Yes	34
No	92
Use of hemostatic materials	
Yes	55
No	71
Locking clips for adrenal tissue and central vein	
Yes	95
No	31
Saponification, adhesion	
Yes	73
No	53
Intraoperative blood loss, ml	55.8 (30.0-80.0)
Fat mass residue	
Yes	19
No	107
Other organ injuries (kidney injury, peritoneal rupture)	
Yes	16
No	110

Table I. Continued.

Variable	Number (n)/value
Check puncture channel	
Yes	97
No	29

normal adrenal tissue and central vein area were managed with ultrasonic scalpel or locking clips, followed by tumor and partial adrenal tissue resection. Final hemostasis was done until no bleeding points were noted. Hemostatic gauze was selectively placed, retroperitoneal drain indwelled and the incision was closed. Postoperatively, the drain was removed when the output was <20 ml over 48 consecutive hours. Total drain output ≤60 ml was defined as 'no drainage' and >60 ml as 'drainage present'.

Statistical methods. Data were processed with SPSS 21.0 (IBM Corp.). Measurement data with normal distribution are presented as the mean ± SD and compared between groups via independent samples t-test; those without normal distribution were expressed as median (interquartile range) and compared via Mann-Whitney U test. Count data were expressed as case numbers and compared via χ^2 test or Fisher's exact probability test. Univariate analysis used χ^2 test, Fisher's exact probability test or t-test. Indicators with significant differences in univariate analysis were included in multivariate logistic regression to analyze factors influencing postoperative drain output. P<0.05 was considered to indicate a statistically significant difference.

Results

Results of the retrospective study. The mean age of the 126 patients was 52.3±11.6 years, including 67 males and 59 females. There were 74 left-sided and 52 right-sided tumors; 16 patients had diabetes and 77 patients had hypertension. The mean tumor diameter was 2.6 (1.8-3.0) cm, all non-functional tumors <4 cm were newly developed in the past year or had an annual growth rate >0.5 cm (11). The average operation duration was 81.6 (60.0-100.0) min and the average intraoperative blood loss was 55.8 (30.0-80.0) ml. Postoperative pathology result were as follows: 80 non-functional adenomas, 6 myelolipomas, 8 pheochromocytomas, 25 aldosteronomas, 4 nodular hyperplasias and 3 ganglioneuromas. Specific basic data are shown in Table I.

The univariate results showed that patient age (P=0.022), tumor diameter (P=0.010), use of anticoagulants within 12 h after surgery (P=0.006), handling of adrenal tissue or central vein with locking clips (P=0.006), saponification and adhesion of adipose tissue in the surgical area (assessed independently by two senior physicians intraoperatively; discrepancies were resolved by consensus through laparoscopic video review) (P<0.001), intraoperative blood loss (P<0.001) and intraoperative injury to other organs (P=0.031) were associated with the formation of postoperative drain output, with statistically significant differences between the groups, as shown in Tables II and III.

Table II. Analysis of postoperative drain output after retroperitoneal laparoscopic adrenal tumor resection.

Variable	No drain output group (n=40)	Drain output group (n=86)	$\chi^2/t/z$ value	P-value
Sex			0.440	0.507
Male	23	44		
Female	17	42		
Age, years	48.8±12.5	54.0±10.8	-2.366	0.020
BMI, kg/m ²	25.3±3.6	25.6±3.5	-0.395	0.693
Pathology			3.276	0.657
Non-functional adenoma	24	56		
Myelolipoma	3	3		
Pheochromocytoma	1	7		
Aldosteronoma	10	15		
Nodular hyperplasia	1	3		
Ganglioneuroma	1	2		
Location			1.843	0.175
Left side	20	54		
Right side	20	32		
Hypertension			1.007	0.316
Yes	27	50		
No	13	36		
Diabetes			0.280	0.597
Yes	6	10		
No	34	76		
Long term use of anticoagulants			0.020	0.888
Yes	5	10		
No	35	76		
Operation duration, min	77.8 (60.0-90.0)	83.4 (55.0-105.0)	-0.468	0.640
Tumor diameter, cm	2.2 (1.6-2.6)	2.8 (2.0-3.3)	-2.867	0.004
12 h postoperative anticoagulant use			8.580	0.004
Yes	4	30		
No	36	56		
Hemostatic materials use			0.960	0.327
Yes	20	35		
No	20	51		
Locking clip application			9.241	0.002
Yes	37	58		
No	3	28		
Saponification, adhesion			22.277	0.001
Yes	11	62		
No	29	24		
Interoperative blood loss, ml	34.5 (20.0-37.5)	65.6 (40.0-80.0)	-5.525	0.001
Fat mass residue			1.181	0.423
Yes	4	15		
No	36	71		
Other organ injuries			6.648	0.012
Yes	1	17		
No	39	69		
Check puncture channel			2.125	0.145
Yes	34	63		
No	6	23		

Table III. Multivariate analysis results of postoperative drain output after retroperitoneal laparoscopic adrenal tumor resection.

Factor	Comparison vs. reference	β value	SE value	Wals value	Multivariate OR (95% CI)	Multivariate P-value	Univariate OR (95% CI)	Univariate P-value
Age	Per 1-year increase	0.060	0.028	4.544	1.062 (1.005-1.123)	0.033	1.039 (1.005-1.074)	0.022
Tumor diameter	Per 1-cm increase	0.788	0.325	5.868	2.199 (1.162-4.159)	0.015	1.828 (1.158-2.886)	0.010
Use of anticoagulants within 12 h	Yes vs. no	-0.824	0.882	0.873	0.439 (0.078-2.471)	0.350	0.207 (0.067-0.638)	0.006
Locking clip application	Yes vs. no	2.492	0.979	6.471	12.081 (1.772-82.385)	0.011	5.954 (1.689-20.992)	0.006
Saponification, adhesion	Yes vs. no	-2.388	0.636	14.102	0.092 (0.026-0.319)	<0.001	0.147 (0.063-0.340)	<0.001
Intraoperative blood loss	Per 1-ml increase	0.047	0.011	17.184	1.048 (1.025-1.072)	<0.001	1.042 (1.024-1.061)	<0.001
Other organ injuries	Yes vs. no	-0.692	1.172	0.349	0.500 (0.050-4.972)	0.555	0.104 (0.013-0.812)	0.031
Constant	-	-4.504	2.340	3.703	0.011	0.054	-	-

OR, odds ratio; CI, confidence interval.

The multivariate results showed that patient age [odds ratio (OR)=1.062; 95% confidence interval (CI): 1.005-1.123; P=0.033], tumor diameter (OR=2.199; 95% CI: 1.162-4.159; P=0.015), handling of adrenal tissue or central vein with locking clips (OR=12.081; 95% CI: 1.772-82.385; P=0.011), saponification and adhesion of adipose tissue in the surgical area (OR=0.092; 95% CI: 0.026-0.319; P<0.001) and intraoperative blood loss (OR=10.48; 95% CI: 1.025-1.072; P<0.001) were independent risk factors for drainage formation after retroperitoneal laparoscopic adrenal tumor resection, as shown in Table III.

Results of the prospective validation study based on screening criteria. To make screening criteria more stringent, the present study selected relevant influencing factors from retrospective univariate results as criteria for non-postoperative drain output. Retrospective univariate results showed patient age, tumor diameter, postoperative 12-h anticoagulant use, locking clip use for adrenal tissue/central vein, surgical area saponification/adhesion, intraoperative blood loss and intraoperative organ injury were associated with postoperative drain output. For the three numerical variables (age, tumor diameter, intraoperative blood loss), the median was used as cut-off. Thus, prospective validation study inclusion criteria for non-drain output patients were: Adults <54 years old, tumor diameter <2.3 cm, no postoperative 12-h anticoagulants, locking clips for adrenal tissue/central vein, no surgical area saponification/adhesion, intraoperative blood loss <80 ml and no intraoperative organ injury.

A prospective validation study included 54 patients: 20 meeting preliminary screening criteria (experimental group) and 34 non-eligible (control group). The 54 patients had an age of 47.3±14.8 years (22 males and 32 females), with 38 left-sided and 16 right-sided tumors. The average tumor diameter was 3.1±1.3 cm, all non-functional tumors <4 cm were newly developed in the past year or had an annual growth rate >0.5 cm. Operation duration was 88.1±26.4 min, intraoperative blood loss 71.7±45.8 ml. The postoperative pathology demonstrated that there were: 30 non-functional adenomas, 5 myelolipomas, 5 pheochromocytomas and 14 aldosteronomas. Specific basic data are shown in Table IV.

A total of one patient in the experimental group had drain output >60 ml and recovered after conservative treatment. This patient had a total drain output of 120 ml, underwent drain removal on postoperative day 4 and was discharged on day 5 without additional interventions. The length of hospital stay was not prolonged relative to the mean hospitalization time of the experimental group. The experimental group had an average total postoperative drain output of 32.8 ml (range 10.0-50.0 ml), vs. an average of 130.0 ml (range 57.5-180.0 ml) in the control group; postoperative extubation time was 2.7±0.8 days (experimental) vs. 4.0±1.1 days (control); postoperative discharge time was 3.7±0.8 days (experimental) vs. 5.0±1.1 days (control). Statistical analysis showed the three indicators were significantly improved in the experimental group (P<0.05), as shown in Table V.

Complications were graded by the Clavien-Dindo system (12). The experimental group had 1 Grade I complication (local wound redness, swelling, exudation, recovered after dressing change) and no Grade II-V complications. The

Table IV. General data of patients in prospective validation study.

Item	Number (n)/value		P-value
	Experimental group	Control group	
Sex			0.510
Male	7	15	
Female	13	19	
Age, years	39.2±9.3	52.1±15.4	0.001
Pathology			0.997
Non-functional adenoma	11	19	
Myelolipoma	2	3	
Pheochromocytoma	2	3	
Aldosteronoma	5	9	
Tumor location			0.507
Left	13	25	
Right	7	9	
Operation duration, min	86.0±27.0	89.4±26.4	0.651
Tumor diameter, cm	1.9 (1.7-2.2)	3.8 (2.8-4.5)	<0.001
Use of anticoagulants within 12 h after operation			0.001
Yes	0	14	
No	20	20	
Locking clip application			0.002
Yes	20	22	
No	0	12	
Saponification, adhesion			0.019
Yes	0	9	
No	20	25	
Intraoperative blood loss, ml	42.0 (22.5-60.0)	89.1 (50.0-122.5)	<0.001
Other organ injuries			0.145
Yes	0	5	
No	20	29	

control group had 1 Grade I complication (same as the experimental group) and 2 Grade II complications: 1 postoperative pneumonia (recovered after anti-infective treatment) and 1 retroperitoneal hematoma-induced lumbago/fever (recovered after antibiotic symptomatic treatment); no Grade III-V complications occurred. Statistics showed no significant difference in complication incidence between the two groups ($P>0.05$), as shown in Table VI.

Discussion

Adrenal tumors, a key urology research field, include functional and non-functional types. Functional tumors, such as aldosteronomas and pheochromocytomas, can cause severe endocrine disorders via abnormal hormone secretion; non-functional tumors are often asymptomatic early but compress surrounding tissues as they grow, harming health. Currently, retroperitoneal laparoscopic adrenal tumor resection is the preferred clinical surgical approach. Notably, with precision medicine advances, adrenal tumor treatment strategies have changed; total adrenalectomy was once recommended for

aldosteronomas, but now simple tumor resection is emphasized to preserve hormone reserves, reduce adrenal crisis incidence and avoid lifelong cortisol replacement therapy (13,14). Thus, the present study also used simple tumor resection for aldosteronomas.

Retroperitoneal laparoscopic adrenal tumor resection is mainstream due to its minimally invasive efficiency, but postoperative complications (especially bleeding) remain a bottleneck for rapid patient recovery, prompting exploration of improved hemostasis and drain management (15). Clinical observations show polarized postoperative drain output in these patients; some have much more than expected, others almost none. This individual difference inspires stratified management via accurate drain output identification, avoiding medical resource waste and enabling precise diagnosis/treatment. Thus, the present study first divided patients into drain and drainage-free groups by postoperative drain output volume, then analyzed factors influencing drain output. In the present study, total postoperative drain output ≤ 60 ml was defined as 'no drainage' and >60 ml as 'drainage present'; this definition is based on physiology and clinical practice: i) Some

Table V. Perioperative index results of prospective validation study.

Item	Experimental group	Control group	t/z Value	P-value
Total drain output volume, ml	32.8 (10.0-50.0)	130.0 (57.5-180.0)	-4.946	<0.001
Drain output tube removal time, days	2.7±0.8	4.0±1.1	-4.802	<0.001
Discharge time, days	3.7±0.8	5.0±1.1	-4.802	<0.001

Table VI. Postoperative complication results of prospective validation study.

Complication grade	Experimental group, n	Control group, n	P-value
0	19	31	-
I	1	1	-
II	0	2	-
III	0	0	-
IV	0	0	-
V	0	0	-
Total	20	34	0.512

Complications were graded by the Clavien-Dindo system.

tissue exudate/lubricating fluid remains retroperitoneally post-operatively, so zero drain output is unrealistic; and ii) ≤60 ml fluid is hypothesized to be fully cleared by retroperitoneal self-absorption/metabolism without adverse effects (such as infection, pain and tissue compression), consistent with observations in the present study, where among the ≤60 ml cases, only 1 Grade I complication occurred (unrelated to drain output volume), supporting biological equivalence to ‘no drain output’. This 60 ml-based standard conforms to human physiology (16) and provides a quantifiable objective basis for clinical practice.

Research shows adrenal tumors >2 cm need surgical resection (bringing clinical benefits) (16). In the present study, all non-functional tumors <4 cm were newly found in the past year or grew >0.5 cm annually, matching established resection criteria (11). The adrenal gland has rich blood supply; its thin-walled central vein arises from the adrenal hilum, runs closely with the inferior vena cava (right) or renal vein (left) for a short segment before anastomosis. During laparoscopic resection, locking clips enable rapid, precise blood flow occlusion via mechanical compression, offering more reliable hemostasis than electrocoagulation (17). The present study also found locking clips for adrenal tissue/central vein are an independent factor influencing postoperative drain output, verifying their bleeding control advantages. Whether tumor size affects intraoperative bleeding remains controversial. de Fourmestreaux *et al* (18) retroactively analyzed 72 patients with pheochromocytoma and found no significant increase in retroperitoneal laparoscopic resection blood loss for tumors >6 cm; however, other prospective cohort studies (comparing tumors ≥6 cm vs. <6 cm) found that larger tumors had notably

more estimated blood loss and higher postoperative complication rates via multivariate analysis (19). Thus, the present study included tumor size and intraoperative blood loss in analysis and results showed both are risk factors for postoperative drain output. Although sufficient hemostasis was achieved (no marked oozing) before abdominal closure, intraoperative blood loss was still an independent factor, possibly due to occult bleeding from intraoperative microvascular injury and delayed bleeding from postoperative surgical field coagulation fluctuations, suggesting precise operation is needed to avoid intraoperative bleeding and reduce postoperative drain output risk. Additionally, the present study found that intraoperative surgical field saponification/adhesion and patient age are relevant factors. Specifically, saponification/adhesion may induce sterile inflammatory exudation (20); meanwhile, elderly patients often exhibit decreased coagulation function, which can lead to continuous oozing from the surgical field (21).

Previous studies have indicated that postoperative use of anticoagulants may inhibit coagulation function, prolong coagulation time and increase the risk of oozing from surgical wounds or visceral bleeding (22-24). Therefore, clinical practice requires individualized assessment based on the thromboembolic risk and bleeding risk of the patient, with strict control over the timing of anticoagulant administration. In the present study, the use of anticoagulants within 12 h after surgery was included in the analysis, but the results showed that this factor had no significant association with the formation of drain output after retroperitoneal laparoscopic adrenal tumor resection, which may be attributed to insufficient sample size. In previous research, innovative hemostatic materials have developed rapidly. For example, the ‘sandwich-like fiber/sponge’ composite hemostatic material reported by Zhang *et al* (25) has both efficient hemostatic effects and local chemotherapy functions, suggesting that the application of hemostatic materials may affect postoperative drain output volume. However, the results of the present study showed that the intraoperative application of hemostatic materials had no significant association with the formation of postoperative drain output, and further verification by expanding the sample size is needed in subsequent studies. In addition, although the present study did not find a statistically significant effect of puncture channel inspection on the formation of postoperative drain output, in view of the potential serious consequences of puncture channel bleeding for individuals, it is still recommended that channel inspection be included as a routine procedure.

To make the screening criteria more rigorous, the present study selected relevant influencing factors from the univariate results in the retrospective study, took them as the screening conditions for the absence of postoperative drain output and

conducted a further prospective validation study. The results showed that the experimental group was superior to the control group in terms of total postoperative drain output volume, postoperative extubation time and postoperative discharge time, with no significant difference in complications between the two groups. No severe (Grade III-V) complications occurred in the experimental group, confirming the safety of the drainage-free strategy. These findings further verify the reliability and feasibility of the screening criteria formulated in the present study, suggesting that the criteria have clinical promotion value.

Scholars have explored day surgery for retroperitoneal laparoscopic adrenalectomy, but these studies lacked patient stratified screening, leaving risks of postoperative infection and bleeding (16,26,27). This results of the present study support stratified management for adrenal tumor patients; screening those with no postoperative drain output may help build a more optimized day surgery model for this resection, although its clinical value needs further verification. Anatomically, the abdominal cavity is large (postoperative bleeding causes severe consequences), while the retroperitoneal space is small and closed (hematomas are localized with better controllability). Per day surgery safety principles, retroperitoneal laparoscopy (not transabdominal) should be prioritized for this resection, one basis for the present study's focus on the retroperitoneal approach. Hou *et al* (28) also compared the two approaches, finding retroperitoneal laparoscopy has improved intraoperative bleeding control (direct access to the adrenal region, less unnecessary intra-abdominal dissection), confirming the approach choice of the present study. It should be noted that adequate preoperative preparation (29) and surgeons clinical experience (30) are key prerequisites for safe retroperitoneal laparoscopic adrenal tumor resection.

The present study has several limitations that should be noted. First, its retrospective component carries selection bias and potential inconsistencies in perioperative variable documentation, which may affect the accuracy of identifying factors influencing postoperative drain output. Second, sample sizes were small (126 in retrospective cohort, 54 in prospective cohort), reducing statistical power and limiting screening criteria generalizability. Third, while the cut-offs for age, tumor diameter and intraoperative blood loss were pragmatically derived from the median values of the retrospective cohort for clinical practicality and exploratory study purposes, their potential applicability to other populations remains unvalidated, which may limit the external validity and generalizability of the screening criteria. To address these and strengthen criteria evidence, future studies should conduct multi-center, large-sample prospective research with standardized objective variable measurements and external cut-off validation, providing more reliable evidence-based support for clinical practice.

In summary, the present study established screening criteria for identifying patients who may be suitable for a drainage-free strategy after retroperitoneal laparoscopic adrenal tumor resection: adult patients aged <54 years, tumor diameter <2.3 cm, no use of anticoagulants within 12 h postoperatively, handling of adrenal tissue or central vein with locking clips, no saponification and adhesion in the surgical area, intraoperative blood loss <80 ml and no intraoperative injury to other organs.

A prospective validation study was performed to evaluate these criteria. The results showed that the drainage-free group had significantly improved outcomes in total postoperative drain output, drain removal time and postoperative hospital stay, suggesting that these criteria may be reliable and feasible. In addition, subgroup-stratified management for these patients may have clinical significance and application potential. Further studies with larger sample sizes and multi-center designs are needed to verify these preliminary findings.

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Availability of data and materials

The data generated in the present study may be requested from the corresponding author.

Authors' contributions

YZ, YXH and HTL conceived the original idea and operated on the patients. JYC, BZ and HZ conducted preliminary research, including collecting clinical data, sorting out clinical information, analyzing relevant data and participating in clinical surgical operations. YZ, YXH, HTL and BZ were involved in writing. YZ and HZ reviewed the manuscript, and confirmed the authenticity of all the raw data. All authors contributed to the final version. All authors read and approved the final version of the manuscript.

Ethics approval and consent to participate

The present study was approved by the Research Ethics Committees of the Affiliated Huai'an No. 1 People's Hospital of Nanjing Medical University (Huai'an, China; approval no. 2025-008) and Xuzhou Cancer Hospital (Xuzhou, China; approval no. 2025-CS-011). The procedures used in this study adhere to the tenets of The Declarations of Helsinki. Informed consent was obtained from all participants in the prospective cohort. For the retrospective cohort, individual informed consent was not required.

Patient consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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