REVIEW

Comparing Complications, Functional And Oncological Outcomes Of Partial Versus Total Adrenalectomy: A Systematic Review And Meta-Analysis Of Literature

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Purpose: Surgical management is a key component in treating adrenal masses, particularly when they are functional or large. However, the choice between partial adrenalectomy (PA) and total adrenalectomy (TA) remains controversial. Therefore, this systematic review and meta-analysis aimed to evaluate whether surgical outcomes differ between patients undergoing PA versus TA.

Materials and methods: Following PRISMA 2020 guidelines, we systematically searched PubMed, Scopus, Web of Science, and the Cochrane Library for studies published up to April 2025. Nineteen studies were included, and methodological quality was assessed using the Newcastle–Ottawa Scale (NOS). A random-effects meta-analysis was conducted to estimate pooled outcomes.

Results: A total of 19 studies comprising 3,165 patients were included, of whom 1,084 underwent partial adrenalectomy (PA) and 2,081 underwent total adrenalectomy (TA). PA was associated with a significantly higher risk of tumor recurrence compared with TA (RR = 2.64, 95% CI 1.55-4.51), while no significant differences were observed for metastasis or mortality. In contrast, PA significantly reduced the risk of postoperative steroid dependence (RR = 0.44, 95% CI 0.34-0.55) and adrenal insufficiency (RR = 0.49, 95% CI 0.34-0.70). Perioperative complications were less frequent following PA (RR = 0.56, 95% CI 0.40-0.78), particularly mild complications, with no differences in severe complications. There were no significant differences in operative time or intraoperative blood loss between the two techniques. Subgroup analyses demonstrated higher recurrence rates in pheochromocytoma among patients undergoing PA, compared with Conn's adenoma. Perioperative complications were less frequent in PA in patients with Conn's adenoma. No significant differences were observed regarding surgical laterality (left vs. right) or the operative approach (transperitoneal vs. retroperitoneal laparoscopic / robotic surgery).

Conclusion: PA offers superior preservation of adrenal function and fewer mild perioperative complications compared with TA, but shows a higher risk of tumor recurrence in pheochromocytoma patients. PA was not associated with higher recurrence in Conn's patients. Other surgical and oncological outcomes were similar, underscoring the need to individualize the choice of procedure based on tumor type and patient factors.

Keywords: partial adrenalectomy; cortical-sparing adrenalectomy; total adrenalectomy; complications; functional outcomes; pheochromocytoma; Cushing syndrome; Conn's syndrome

INTRODUCTION

Adrenal masses encompass a wide range of pathologies, ranging from benign non-functional adenomas to hormonally active tumors and adrenocortical carcinoma.[1] Consequently, individuals with adrenal masses can experience a broad spectrum of symptoms. These range from asymptomatic patients to those presenting with clinical manifestations induced by Cushing's syndrome or pheochromocytoma, including hypertensive crisis, palpitations, excessive sweating, facial flushing, and hypermetabolism.[2,3] Although the majority of adrenal masses consist of benign functional lesions, less than 10% are malignant and can have autonomous secretion of adrenal hormones, leading to considerable morbidity if left untreated.[4,5] Therefore, to effectively manage and prevent further complications caused by these lesions, surgical interventions are required and recommended, even for large non-functional tumors, as they carry a high potential for developing adrenocortical carcinoma.[6]

Adrenalectomy is considered the definitive treatment for multiple adrenal abnormalities and a standard surgical approach for a variety of adrenal pathologies.[7] However, there is still uncertainty regarding whether it is necessary to perform a total adrenal resection or to preserve the organ using partial adrenalectomy in some instances. Partial adrenalectomy is a surgical approach that involves removing the pathologic adrenal lesion while preserving a portion of vascularized adrenal tissue to support the maintenance of adrenocortical hormone function.[8] While total adrenalectomy (TA) has traditionally been preferred, particularly for malignant or functional tumors, partial adrenalectomy (PA) can be

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Table 1. Summary characteristics of the included studies

First Author	Year	Study Design	Sample Size (PA/TA)	Mean (Median) Age (PA/TA)	Follow-up Duration (months)	Tumor Pathology	Surgical Technique	Surgical Approach	Country
Ishidoya 2004	2004	comparative (retrospective)	29/63	49.3 / 50.2	60.3 (PA) & 29.3 (TA)	Conn`s syndrome	Laparoscopic surgery	Trans/ Retroperitoneal	Japan
Walz 2004	2004	comparative study (prospective)	96/224	44.5/51	53 (PA) & 51(TA)	Various pathology	Laparoscopic surgery	Retroperitoneal	Germany
Liao 2009	2009	study comparative	6/6	57.5/57.5	61 (PA) & 27 (TA)	Cushing's and Conn's syndrome	Laparoscopic surgery	Transperitoneal	Taiwan
Fu 2010	2010	trial Randomized	104/108	43/41	96	Conn's syndrome	Laparoscopic surgery	Retroperitoneal	China
Chen 2014	2014	comparative study	16/47	48.5/48.7	12	Conn's syndrome	Laparoscopic surgery	Transperitoneal	Taiwan
Castinetti 2014 (retrospective)	2014	comparative	114/438	-	10 (PA) & 13 (TA)	Pheochro-mocytoma	Endoscopic + open surgery	Retroperitoneal	Multinational
Balci 2019	2019	comparative study (prospective)	15/25	42.1/46.9	15	Various pathology	Laparoscopic surgery	Transperitoneal	Turkey
Liu 2020	2020	comparative (retrospective)	65/31	48.2/56.4	32.3 (PA) & 40.8 (TA)	Conn's syndrome	Laparoscopic surgery	Trans/Retroperitoneal	China
Liu 2020	2020	comparative (retrospective)	65/31	48.2/56.4	32.3 (PA) & 40.8 (TA)	Conn's syndrome	Laparoscopic surgery	Trans/Retroperitoneal	China
Billman 2020	2020	comparative (retrospective)	78/156	45.9/53.1	22.8 (PA) & 24.8 (TA)	Conn's syndrome	Laparoscopic surgery	Trans/Retroperitoneal	Germany
Anceschi 2021	2021	comparative	29/61	57/54	46 (PA) & 41 (TA)	Conn's syndrome	Laparoscopic + robotic surgery	Trans/Retroperitoneal	Italy
Alesina 2023	2023	comparative	24/59	42.1/47	107	Cushing's syndrome	Laparoscopic surgery	Retroperitoneal	Germany
Xu 2024	2024	comparative	33/223	26/42	123 (PA) & 96(TA)	Pheochro-mocytoma	Open + Laparoscopic + retroperitoneoscopic surgery	Not mentioned	European
Kittah 2020	2020	comparative (retrospective)	18/75	35	102	Pheochrom ocytoma	Laparoscopic + open surgery	Not mentioned	USA
Neumann 2019	2019	comparative	324/301	30	96	Pheochro-mocytoma	Laparoscopic surgery	Retroperitoneal	Multinational
Sanford 2021	2021	comparative (prospective)	35/31	31	200	Pheochrom-ocytoma	Laparoscopic + open surgery	Retroperitoneal	USA
Scholten 2011	2011	comparative (retrospective)	9/52	33	160	Pheochro-mocytoma	Laparoscopic + open surgery	Retroperitoneal	Netherlands
Yip 2004	2004	comparative	22/16	39.5	71	Pheochro-mocytoma	Laparoscopic + open surgery	Transperitoneal	USA
Grubbs 2012	2012	comparative (retrospective)	55/99	38.25*	108	Pheochrom-ocytoma	Laparoscopic + open surgery	Trans/ Retroperitoneal	USA
Simforoush 2020	2020	comparative	12/66	39.05	78	Various pathology	Laparoscopic surgery	Transperitoneal	Iran

considered more often for clearly benign non-functional lesions and is a probable alternative for hereditary tumors.[9,10] Nevertheless, despite these developments, the impact of these two surgical procedures on perioperative complications and oncological and functional outcomes remains controversial.[11-14] It is important to mention that the assessment of alternative surgical approaches is commonly used in various procedures to improve patient outcomes.[15-23] Applying similar comparisons in adrenalectomy could offer valuable insights into optimizing both functional preservation and oncological results. Despite the routine use of such comparisons in other surgical fields, combined data evaluating outcomes of different adrenalectomy techniques remain limited.

Accordingly, we conducted a systematic review and meta-analysis to explore the comparative outcomes, including functional, oncological, and perioperative complications, in total and partial adrenalectomy.

MATERIALS AND METHODS

Study design and search strategy

This systematic review and meta-analysis was conducted to compare the complications and functional and oncological outcomes associated with partial adrenalectomy (PA) and total adrenalectomy (TA), based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist. The protocol for this research is registered in the PROSPERO international database under the registration number CRD42020203225. The protocol was registered before performing the updated 2025 literature search. The update was undertaken solely to include the most recent publications and ensure the review reflected current evidence. No changes were made to the original PICO elements or planned analyses.

A comprehensive literature search was conducted across multiple electronic databases, including PubMed, Scopus, and Web of Science, and the Cochrane Library for articles published up to April 2025. The search strategy is provided in the Supplementary File. The search terms included "partial adrenalectomy," "cortical-sparing adrenalectomy," "total adrenalectomy," "complications," "functional outcomes," "clinical outcomes," "Pheochromocytoma," "Cushing," and "Conn's syndrome." The search was restricted to peer-reviewed reports. Studies that reported on the outcomes of PA and TA, including complications, functional outcomes, and oncological outcomes, were included. To identify additional eligible articles, the reference lists of the included articles were manually screened.

Table 2. Quality assessment of the included studies (the NOS tool)

Study/ Year	Selection				Comparability		Outcome Score			Total	Quality
	Represent-ativeness of sample	Selection of Non-respondents	Ascertainment of Exposure	Outcome Not Present at Start	the most important risk factors	Adjust for other risk factors	Adjust for of Outcome	Assessment Long Enough	Follow-up of Follow-up	Adequacy	
Ishidoya/ 2004	1	1	1	1	1	0	1	0	1	7	High
Walz / 2004	1	0	1	1	1	0	1	0	1	6	Moderate
Yip / 2004	1	1	1	1	1	0	1	1	1	8	High
Liao / 2009	1	0	1	1	1	0	1	0	1	7	High
Fu / 2010	1	1	1	1	1	0	1	0	1	7	High
Scholten / 2011	1	1	1	1	1	0	1	1	1	8	High
Grubbs / 2012	1	1	1	1	1	0	1	1	1	8	High
Chen / 2014	1	1	1	1	1	0	1	0	1	7	High
Castinetti / 2014	1	0	1	1	1	0	1	0	1	6	Moderate
Balci / 2019	1	1	1	1	1	0	1	0	1	7	High
Neumann / 2019	1	1	1	1	1	0	1	1	1	8	High
Liu / 2020	1	1	1	1	1	0	1	0	1	7	High
Billman /2020	1	1	1	1	1	0	1	0	1	7	High
Simforoush / 2020	1	1	1	1	1	0	1	1	1	8	High
Kittah / 2020	1	1	1	1	1	0	1	1	1	8	High
Anceschi / 2021	1	1	1	1	1	0	1	1	1	8	High
Sanford / 2021	1	1	1	1	1	0	1	1	1	8	High
Alesina / 2023	1	1	1	1	1	0	1	0	1	7	High
Xu 2024	1	1	1	1	1	0	1	1	1	8	High

Eligibility criteria

All peer-reviewed original studies that compared PA and TA among human subjects and reported at least one relevant outcome—including functional and/or oncological outcomes and/or perioperative complications—were included in this systematic review and meta-analysis. Research papers with non-comparative designs, reviews, editorials, or conference abstracts were excluded. Additionally, studies with inadequate outcome data or overlapping patient populations were excluded from our systematic review. Studies with sample sizes <10 were excluded, as extremely small studies may provide unreliable estimates, limit the precision of pooled results, and increase the risk of random error.

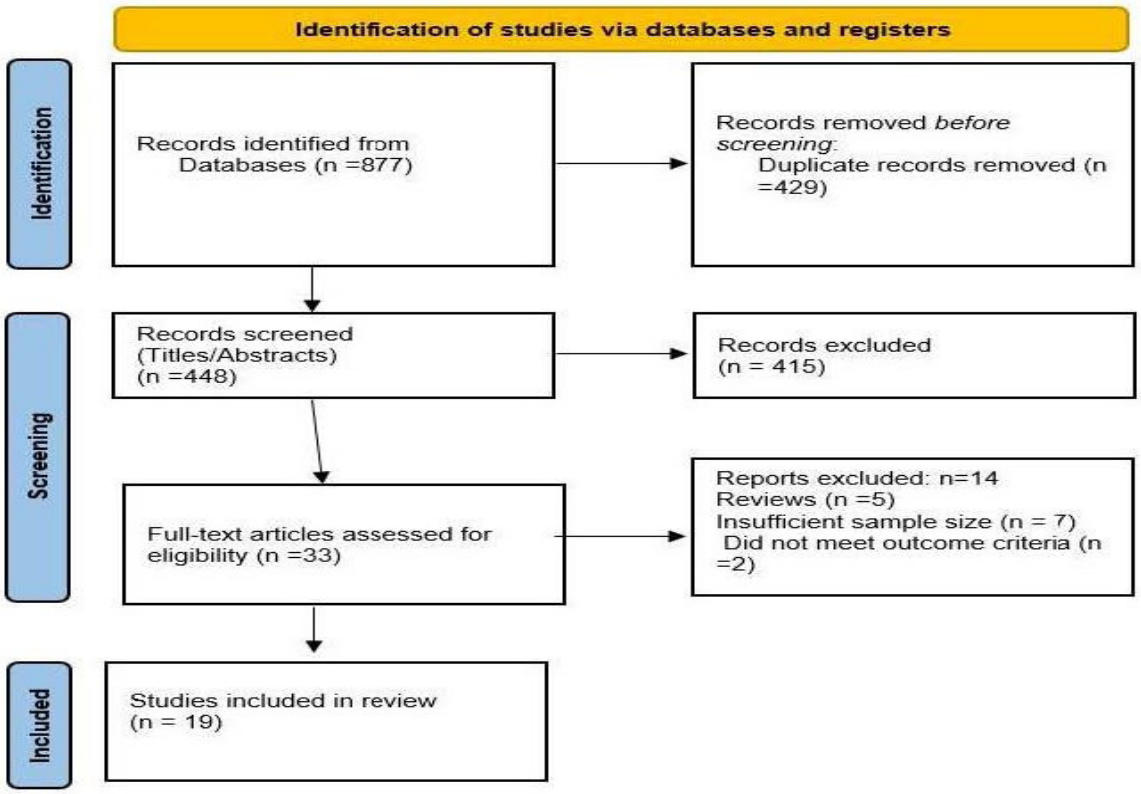

Figure 1. PRISMA flow diagram illustrating the selection process of studies included in the systematic review and meta-analysis

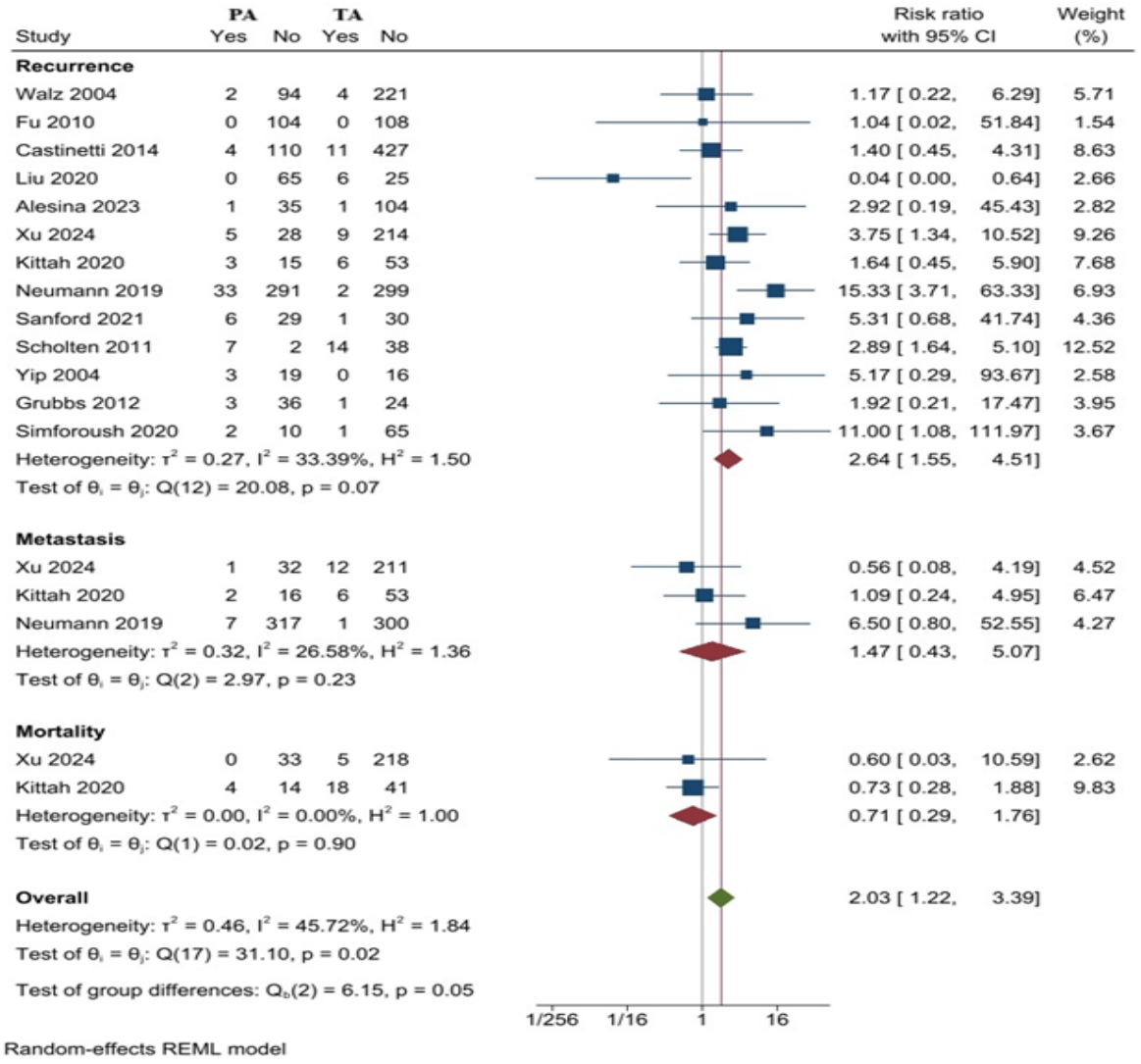

Figure 2. Forest plot of the oncological outcomes in Partial Adrenalectomy (PA) versus Total Adrenalectomy (TA). PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

Study selection

This study used EndNote 21 software to import all database records. Two reviewers independently evaluated the articles according to the eligibility criteria. Duplicate records were removed, and the titles, abstracts, and full texts of the selected articles were utilized in the screening process. Studies that met the eligibility criteria were advanced to data extraction. A third reviewer was consulted to resolve any disagreements between the two reviewers.

Data extraction

The following data were extracted from each article by two reviewers separately: first author, year of publication, country, mean age of subjects, population characteristics (mean age of subjects, tumor pathology, type of surgery), and functional and oncological outcomes. When continuous outcomes were reported as medians and interquartile ranges (IQRs), these values were converted to means and standard deviations (SDs) using the method proposed by Wan et al.(24) Discrepancies were resolved through discussion or consultation with a third reviewer. Complications were also extracted and categorized by the Clavien-Dindo classification.

Quality assessment

The quality of the included studies was evaluated using the Newcastle–Ottawa Scale (NOS) for observational studies.[25] For each study, a maximum of 9 points was assigned according to the following parameters: 4 points for participant selection, 2 points for comparability, and 3 points for outcome assessment. Studies were categorized as high-quality (7-9 points), moderate-quality (4-6 points), or at high risk of bias (0-3 points). The single randomized controlled trial (RCT) included in the analysis was assessed separately using the Cochrane Risk of Bias 2.0 (RoB 2.0) tool, which evaluates risk of bias across five domains specific to randomized studies. (26) Two independent reviewers performed the quality assessment, and discrepancies were resolved through discussion or consultation with a third reviewer.

Definition of terms

Recurrence: Defined as tumor regrowth in the adrenal bed or remnant tissue (local recurrence), or occurrence

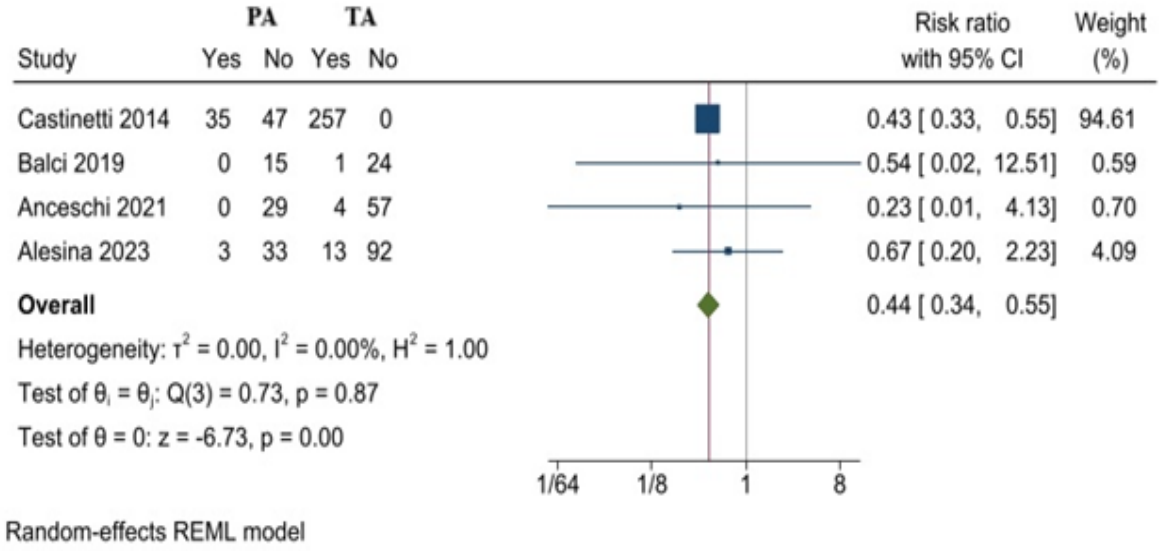

Figure 3. Forest plot of the presence of postoperative steroid dependency in Partial Adrenalectomy (PA) versus Total Adrenalectomy (TA). PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

of new lesions in the contralateral adrenal gland (contralateral/new recurrence).
Metastasis: Defined as radiologically or histologically confirmed distant spread to extra-adrenal sites.
Mortality: Reported as either disease-specific mortality (death attributable to adrenal pathology or surgical complications) or all-cause mortality, as specified in each study.
Steroid dependency: Defined as continued need for exogenous glucocorticoid replacement beyond the immediate postoperative period, typically for >6 months after surgery, with reported daily dose and duration when available.
Adrenal insufficiency: Defined as a clinical syndrome caused by inadequate glucocorticoid production or action, with or without mineralocorticoid and adrenal androgen deficiency. Clinical presentation ranges from nonspecific symptoms to life-threatening adrenal crisis. Diagnosis is based on clinical suspicion, low morning serum cortisol (<140 nmol/L or 5 µg/dL), ACTH measurement, and, when indicated, confirmatory cosyntropin testing.[27]
Perioperative complications: Any deviation from the normal postoperative course was recorded and classified according to the Clavien–Dindo system.(28)

Statistical analysis

A meta-analysis was conducted using STATA version 17. For dichotomous outcomes, odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. Continuous outcomes were analyzed using weighted mean differences (WMDs) when applicable. A random-effects model was used to account for between-study heterogeneity. All results were illustrated in a forest plot. Heterogeneity was assessed using the I^2 statistic, with values greater than 50% indicating substantial heterogeneity. Subgroup analyses were planned based on Clavien-Dindo grades for complications, tumor pathology (Cushing's syndrome, Conn's syndrome, and pheochromocytoma), and surgical approach. Finally, publication bias was assessed using funnel plots and Egger's test for analyses with 10 or more included studies. Additionally, sensitivity analyses were conducted by sequentially excluding each study to evaluate the robustness of the pooled estimates and assess the influence of individual studies on the overall results.

RESULTS

Characteristics of Eligible Articles

We thoroughly searched databases up to April 2025. Based on our computerized search, a total of 877 articles were identified from various databases, including PubMed, Scopus, Web of Science, and the Cochrane Library. After removing duplicates, records were screened by title and abstract, and all irrelevant articles (e.g., animal or in vitro studies, studies not investigating the complications and outcomes of partial versus total adrenalectomy) were excluded. Subsequently, 33 potentially applicable records underwent a full-text review.
The final analysis comprised 19 reports presenting data from a total of 3,165 patients, with 1,084 patients undergoing PA and 2,081 patients undergoing TA. The mean age of patients in the PA and TA groups was 46.2 and 47.6 years, respectively. The literature screening process is presented in (**Figure 1**). One of the included studies was an RCT, and the other 18 included studies were designed in a comparative observational framework. There were four included studies from the USA, seven from European countries, and six from Asian countries. Two reports were multinational. The characteristics of the included studies are shown in (**Table 1**).

Quality assessment of included studies

The quality of observational studies was assessed using the NOS, and the single RCT was assessed using the RoB 2.0 tool. Among the 18 observational studies, 16 were rated as high quality, while two were rated as moderate quality. Overall, the studies demonstrated strong performance in the Selection domain. Minor limitations were observed in the Comparability and Outcomes domains, particularly regarding adjustments for other risk factors and the duration of follow-up. The

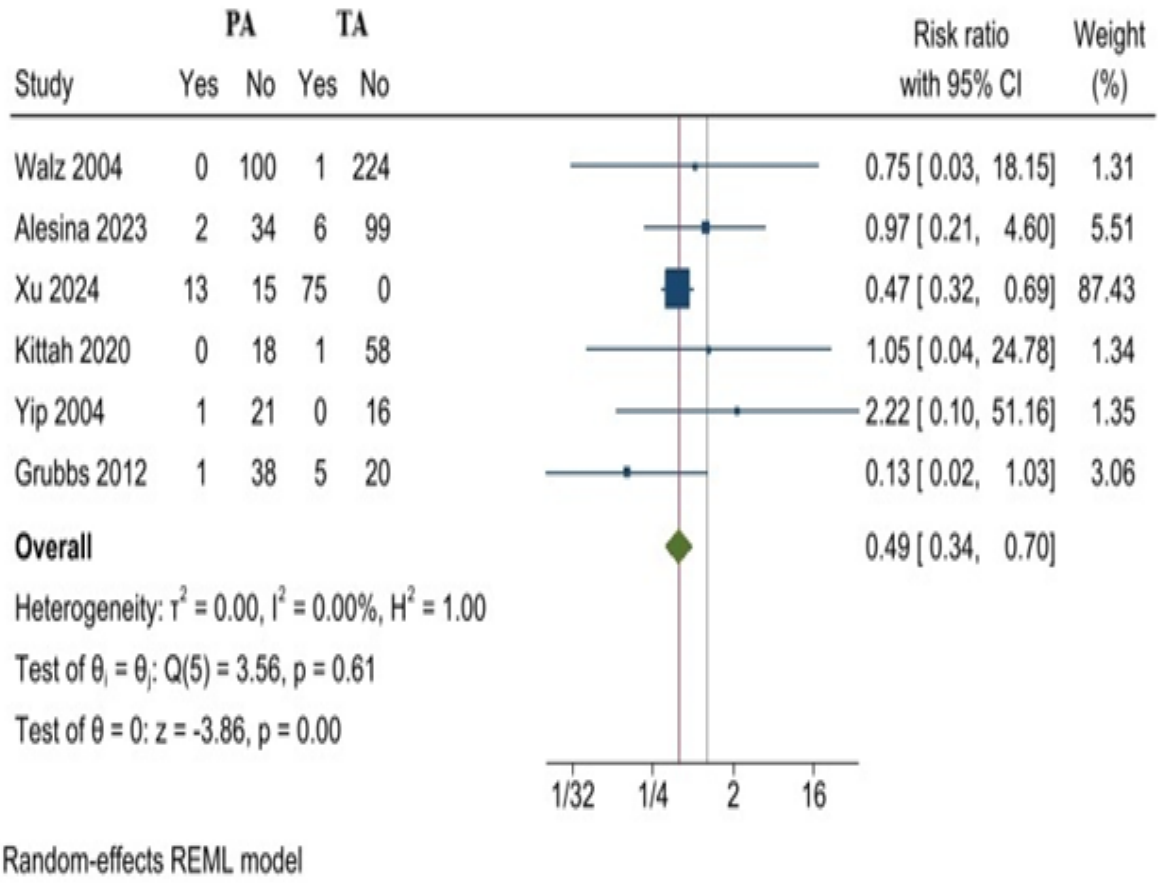

Figure 4. Forest plot of the presence of postoperative adrenal insufficiency in Partial Adrenalectomy (PA) versus Total Adrenalectomy (TA). PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

detailed scoring results are shown in (**Table 2**).
The included RCT was assessed as having "some concerns" regarding risk of bias, largely due to limited information on allocation concealment, lack of blinding, and the absence of a clearly pre-specified analysis plan.

Oncological outcomes

Oncological outcomes were evaluated across recurrence, metastasis, and mortality. Tumor recurrence was reported in thirteen studies. The pooled analysis (**Figure 2**) demonstrated a significantly higher risk of recurrence following partial adrenalectomy (PA) compared with total adrenalectomy (TA) (RR = 2.64, 95% CI 1.55-4.51, $p < 0.001$). Moderate heterogeneity was observed among studies ($I^2 = 33.4\%$, $p = 0.07$). For metastasis, data from three studies were available. The pooled analysis revealed no statistically significant difference between PA and TA (RR = 1.47, 95% CI 0.43-5.07, $p = 0.53$), with low heterogeneity ($I^2 = 26.6\%$, $p = 0.23$). Regarding mortality, only two studies provided eligible data. The pooled analysis showed no significant difference in mortality risk between PA and TA (RR = 0.71, 95% CI 0.29-1.76, $p = 0.45$), with no heterogeneity ($I^2 = 0.00\%$, $p = 0.90$).
When all oncological endpoints were combined, the overall analysis demonstrated a significantly higher pooled risk associated with PA (RR = 2.03, 95% CI 1.22-3.39, $p = 0.02$; $I^2 = 45.7\%$). Furthermore, no publication bias was detected based on Egger's test ($p = 0.38$) or Begg's test ($p = 0.58$).

Functional outcomes

Postoperative steroid dependency was reported in four studies, including 162 patients in the partial adrenalectomy (PA) group and 448 in the total adrenalectomy (TA) group. The pooled analysis (**Figure 3**) demonstrated a significantly lower risk of postoperative steroid dependence in the PA group (RR = 0.44, 95% CI 0.34-0.55, $p < 0.001$). Heterogeneity among the included studies was negligible ($I^2 = 0.00\%$, $p = 0.87$).
Postoperative adrenal insufficiency was assessed in six studies (Figure 4). The pooled analysis showed that PA was associated with a significantly lower risk of adrenal insufficiency compared with TA (RR = 0.49, 95% CI 0.34-0.70, $p < 0.01$). Between-study heterogeneity was absent ($I^2 = 0.00\%$, $p = 0.61$), suggesting consistent findings across studies.

Perioperative complications

Eight studies assessed the incidence of perioperative complications following PA versus TA. The pooled odds ratio, shown in (**Figure 5**), indicated a significantly lower risk of complications in the PA group compared to the TA group (RR = 0.56, 95% CI 0.40-0.78, $p < 0.01$). Between-study heterogeneity was low ($I^2 = 4.2\%$; $p = 0.61$). A subgroup analysis based on the Clavien-Dindo classification, presented in (Figure 6), PA was associated with a lower incidence of grade I

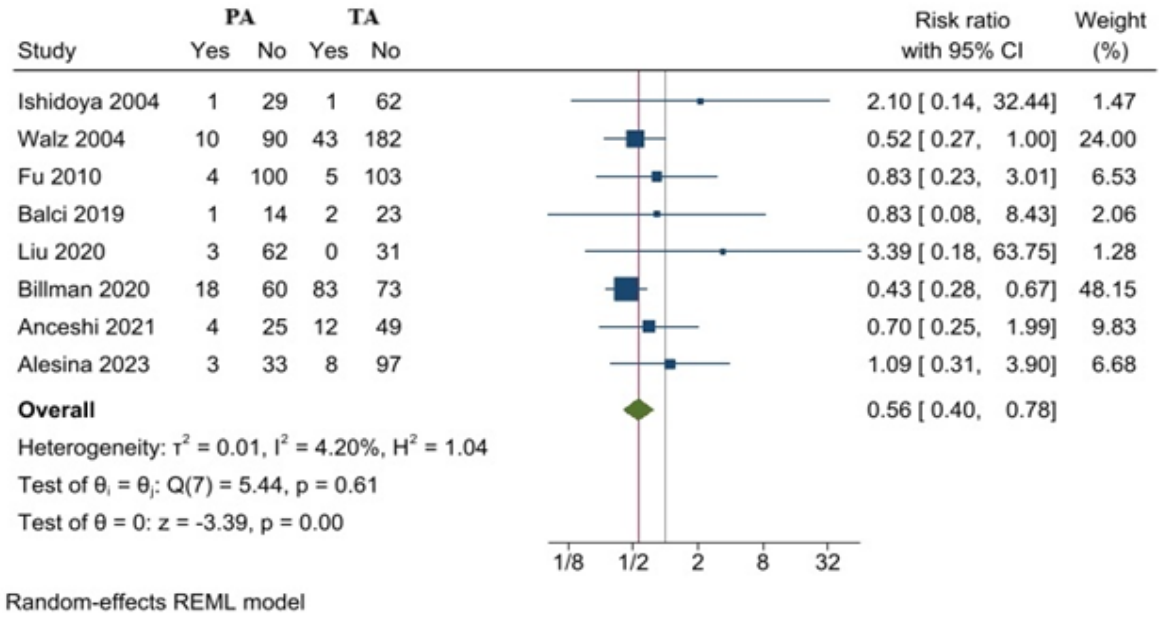

Figure 5. Forest plot of the presence of perioperative complications in Partial Adrenalectomy (PA) versus Total Adrenalectomy (TA). PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

complications compared with TA (RR = 0.62, 95% CI 0.39-0.98, p = 0.04). For Grades II–IV complications, no statistically significant differences were observed between the two approaches. Moreover, we performed another subgroup analysis stratified by the severity of perioperative complications, as shown in the forest plot

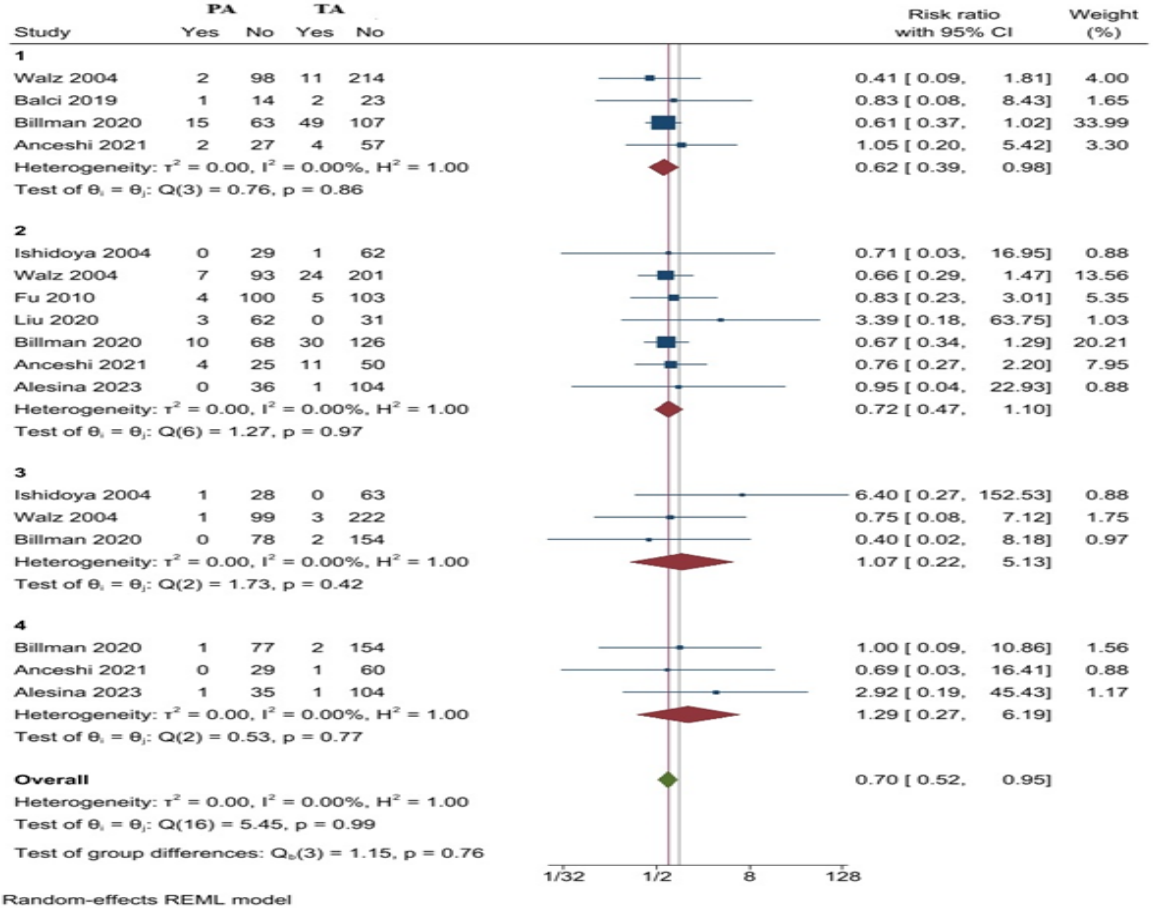

Figure 6. Forest plot of the presence of perioperative complications based on Clavien-Dindo classification in Partial Adrenalectomy (PA) versus Total Adrenalectomy (TA). PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

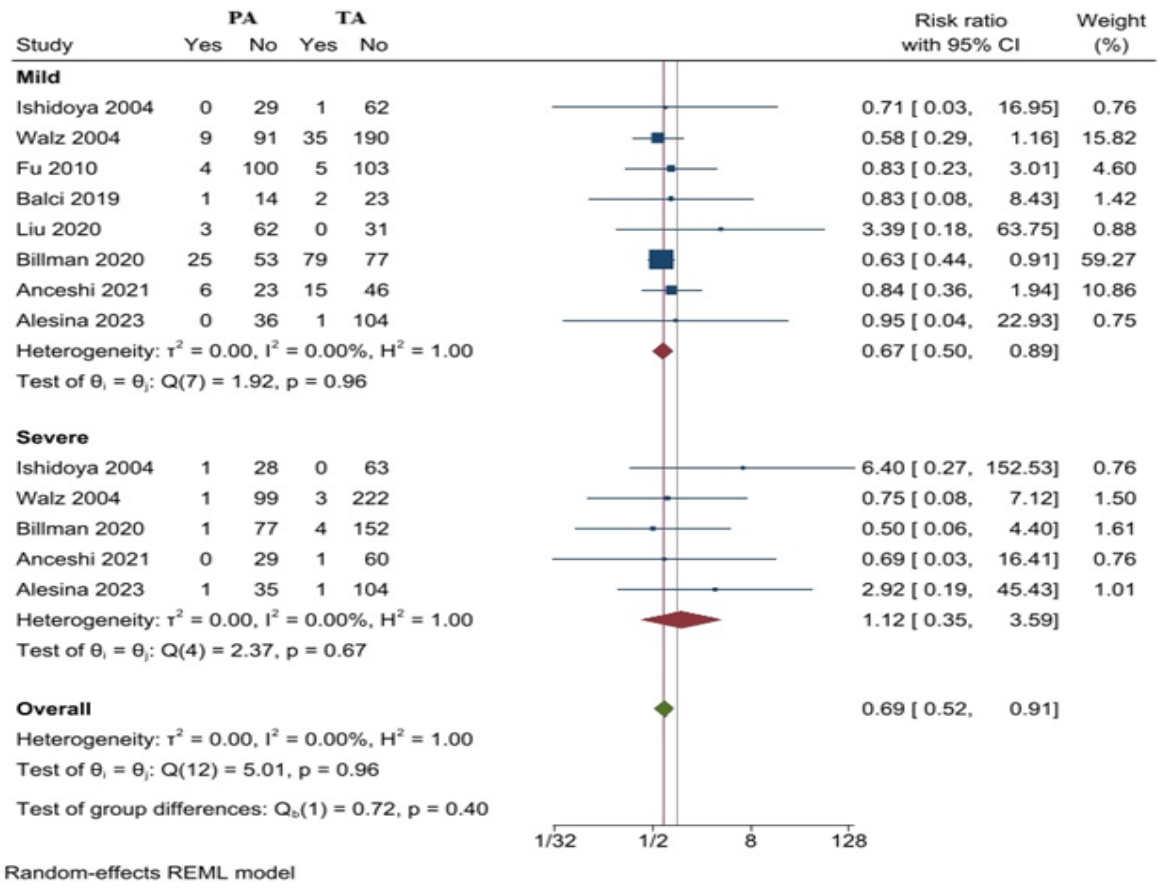

Figure 7. Forest plot of the presence of perioperative complications based on severity in Partial Adrenalectomy (PA) versus Total Adrenalectomy (TA). PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

in (**Figure 7**). Accordingly, the risk of mild complications was significantly lower after PA (RR = 0.67, 95% CI 0.50-0.89, $p = 0.01$), whereas there was no significant difference between PA and TA for severe complications (RR = 1.12, 95% CI 0.35-3.59, $p = 0.67$).

Blood loss

A total of six studies reported data on intraoperative blood loss. The pooled analysis, illustrated in (Figure 8), showed no statistically significant difference between the PA and TA groups (mean difference = 2.78 mL; 95% CI, -10.33 to 15.89; $p = 0.68$). Substantial heterogeneity was observed among studies ($I^2 = 81.8\%$; $p < 0.001$).

Operative duration

Across eight studies, the comparison of operative time between PA and TA, shown in (**Figure 9**), revealed no statistically significant difference (mean difference = -0.12 minutes; 95% CI, -40.37 to 40.14; $p = 0.99$) with considerable heterogeneity across the included studies ($I^2 = 99.5\%$; $p < 0.001$).

Subgroup analyses by tumor pathology

Subgroup analyses were performed according to tumor pathology, including Conn's syndrome, Cushing's syndrome, and pheochromocytoma.

Regarding Conn's syndrome, the risk of tumor recurrence was lower in patients undergoing PA (RR = 0.16, 95% CI, 0.03-1.00, $p = 0.05$) (Figure 10). Furthermore, perioperative complications were also significantly less frequent in the PA group among patients with Conn's syndrome (RR = 0.59; 95% CI, 0.35-0.99; $p = 0.04$) (supplementary figure 1). In pheochromocytoma, the recurrence rate was significantly higher following PA (RR = 2.85; 95% CI, 1.86-4.37; $p < 0.05$) (**Figure 10**). However, PA was associated with a significantly lower incidence of postoperative adrenal insufficiency (RR = 0.46; 95% CI, 0.32-0.68; $p < 0.05$) (supplementary figure 1). For Cushing's syndrome, none of the outcomes showed statistically significant differences between PA and TA, likely due to the limited number of studies available for this subgroup (**Figure 10**), (**supplementary figures 1-4**). No significant differences were observed in operative time or intraoperative blood loss (**supplementary figures 3,4**).

Subgroup analyses by surgical approach

Across studies comparing surgical approaches, retroperitoneal partial adrenalectomy (PA) was associated with a significantly lower risk of adrenal insufficiency compared with total adrenalectomy (TA) (RR = 0.49; 95% CI 0.34-0.72; $p < 0.001$) (supplementary figure 5). No statistically significant differences were observed between surgical approaches in terms of recurrence, perioperative complications, operative time, or intraoperative blood loss (**Figure 11**), (**supplementary figures 6-8**).

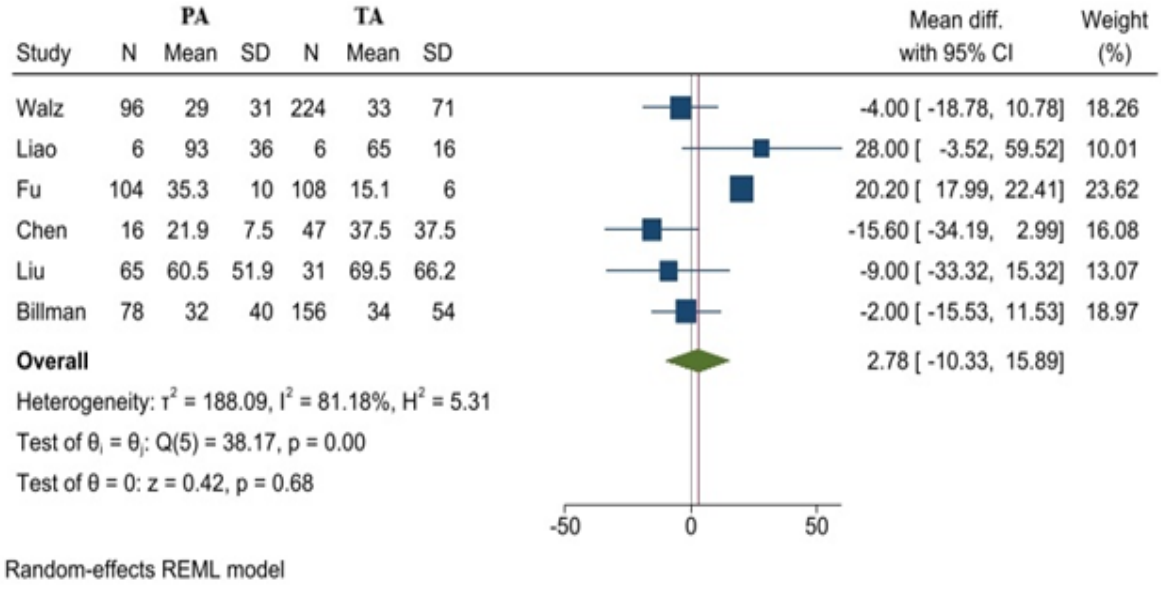

Figure 8. Forest plot of the mean blood loss (ml) in Partial Adrenalectomy (PA) versus Total Adrenalectomy (TA). PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

Subgroup analyses by laterality

When analyzed by laterality, no statistically significant differences were observed between unilateral and bilateral cases in outcomes for which sufficient data were available (**supplementary figures 9-13**).

Sensitivity analysis

Leave-one-out sensitivity analyses showed that no single study significantly influenced the results for recurrence. The findings remained consistent, supporting the reliability of our conclusions. These results are available in supplementary **figure 15**.

DISCUSSION

In this systematic review and meta-analysis of 19 studies with over 3000 patients, we compared partial adrenalectomy (PA) with total adrenalectomy (TA) across oncologic, functional, and perioperative outcomes. PA was associated with a higher risk of recurrence overall, with this association largely driven by pheochromocytoma. The elevated recurrence risk with PA appeared confined to patients with pheochromocytoma, whereas no significant differences were seen in Conn's or Cushing's syndromes. Our pooled results indicated that PA provided better functional preservation, with significantly fewer patients requiring postoperative steroid replacement or developing adrenal insufficiency than after TA.

Regarding complication rates, our analysis demonstrated that individuals who underwent PA generally faced lower rates of perioperative complications than patients undergoing total adrenal removal. Furthermore, periop-

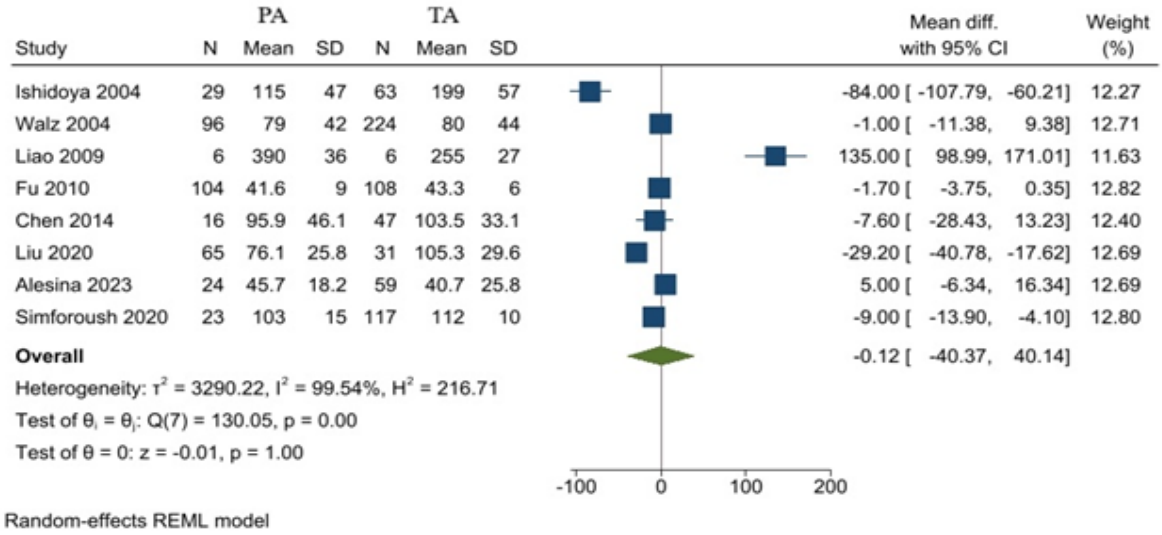

Figure 9. Forest plot of the mean operative duration (min) in Partial Adrenalectomy (PA) versus Total Adrenalectomy (TA). PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

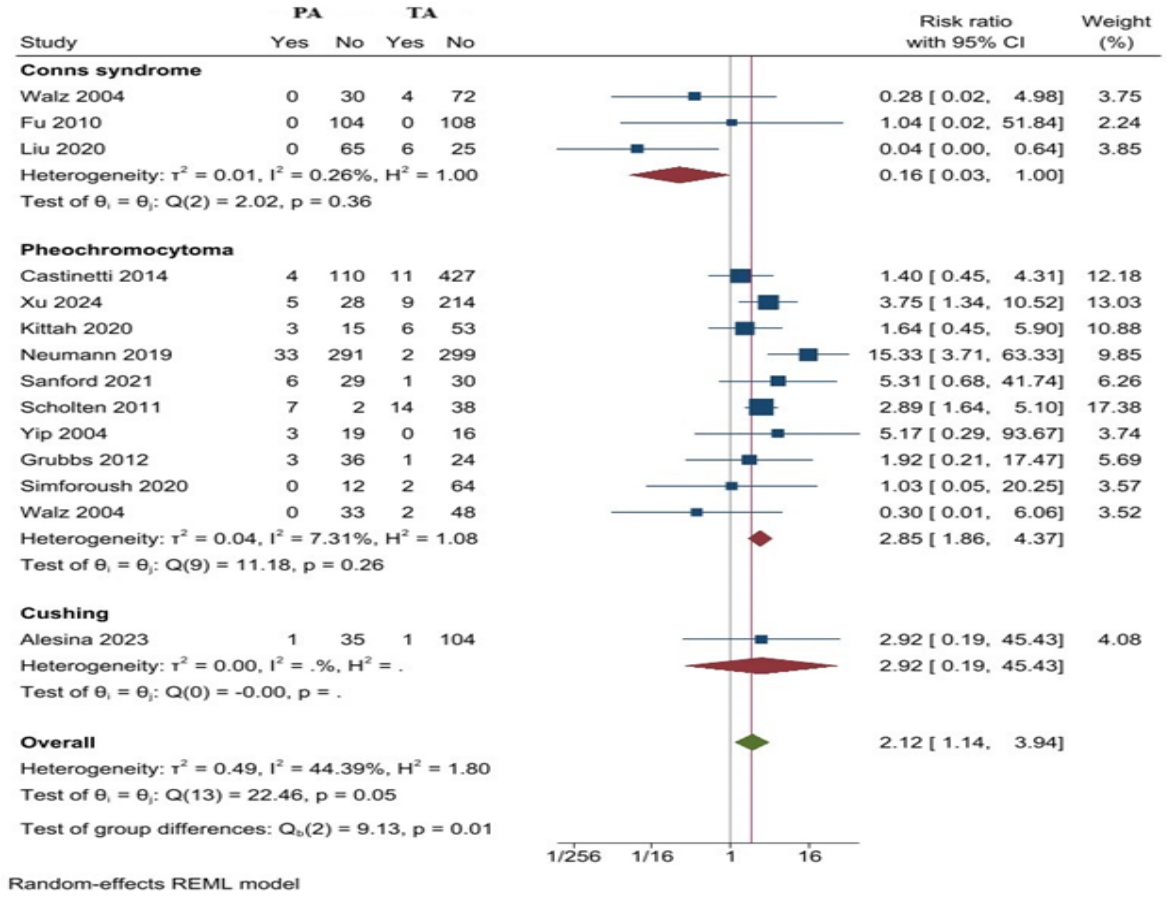

Figure 10. Forest plot of recurrence in (PA) versus Total Adrenalectomy (TA), stratified by tumor pathology. PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval

erative complications were less frequent with PA, with risk ratios of 0.62 and 0.67 for Clavien–Dindo grade I and overall mild complications, respectively, compared with TA. Nevertheless, no significant associations were observed regarding the differences in mean intraoperative blood loss and operation duration between PA and TA. To be noted, analyses stratified by laterality did not show significant differences between unilateral and bilateral cases for outcomes with sufficient data.

Despite numerous comparative and observational studies, the optimal surgical treatment for adrenal lesions remains under debate. According to the latest guideline on adrenalectomy, published in 2022, partial or cortical-sparing adrenalectomy was recommended in patients with bilateral pheochromocytoma to reduce the incidence of adrenal insufficiency and to preserve partial hormonal function of the gland.[29] However, some considerations, including the possible risk of recurrence and increased technical difficulty, should be considered.[29] Our findings and pooled estimates indicated that patients who underwent PA are approximately 2.4 times more likely to experience recurrence. Consistent with our findings, a prior systematic review and meta-analysis found that recurrence rates are higher with the PA procedure in patients undergoing surgery for bilateral pheochromocytoma.[30] However, as mentioned above, our analysis for Conn's syndrome showed no significant correlation when comparing the recurrence rate of PA and TA. This was supported by data from a recent systematic review by Li et al., which indicated that there were no significant differences in recurrence rates between the PA and TA groups.[31] In the case of Cushing's syndrome, evidence is limited to a single study by Alesina et al., which found no significant difference in recurrence rates between the PA and TA groups.[32] Additionally, when comparing the recurrence rate solely within the PA group, pheochromocytoma demonstrated the highest recurrence rate at 10%, while Conn's syndrome showed a substantially lower rate of 2%.[33]

The significantly higher recurrence rates in PA, particularly in patients with pheochromocytoma, can be attributed to the hereditary and multifocal tendencies of pheochromocytoma.[34,35] Compared to Cushing's and Conn's syndromes, which are more likely to involve solitary and benign lesions, pheochromocytoma is less suitable for cortical-sparing adrenalectomy.[36,37] Nevertheless, it is important to note that fewer studies have been conducted on Conn's syndrome and Cushing's syndrome compared to pheochromocytoma, which limits the results and interpretation for these two pathologies. Furthermore, investigating the role of surgical approaches, we revealed that regardless of whether a retroperitoneal or transperitoneal approach was used, PA was associated with a higher recurrence rate than TA. This finding suggests that the increased risk of recurrence with PA may be less attributable to the choice of surgical access and more related to the extent of adrenal tissue resection. Notably, it was previously suggested that the

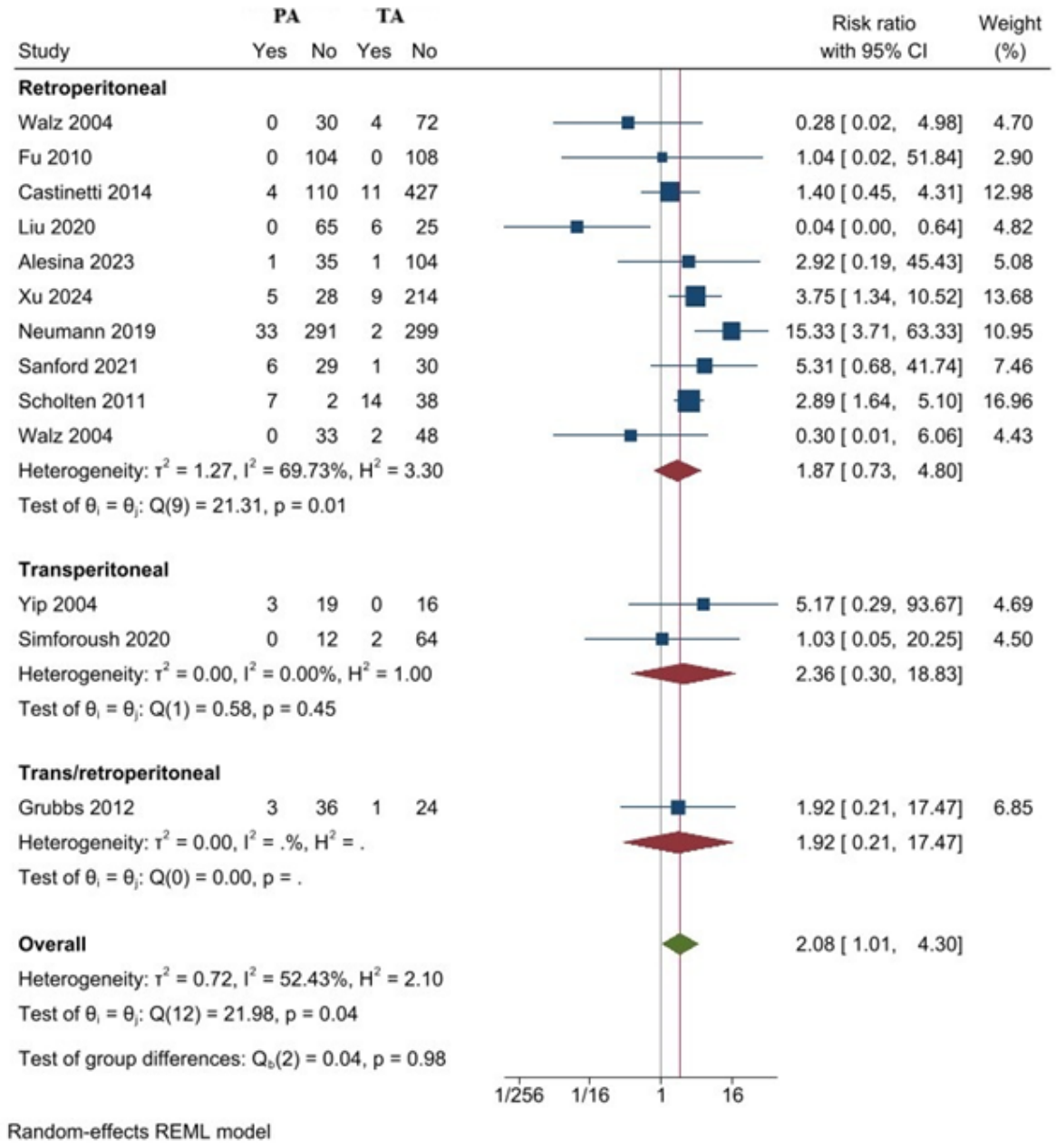

Figure 11. Forest plot of recurrence in (PA) versus Total Adrenalectomy (TA), stratified by surgical approach. PA, partial adrenalectomy; TA, total adrenalectomy; CI, confidence interval.

recurrence rate and steroid dependency were low when PA was performed on smaller adrenal lesions.[38]

Moreover, PA tends to preserve enough adrenal tissue to maintain hormonal function, and in our pooled analysis it was linked to significantly lower rates of postoperative steroid dependency and adrenal insufficiency compared with TA. Because of limited data, subgroup analyses by tumor pathology or surgical approach were not possible, which restricted a deeper examination of these variations. Factors such as follow-up length, the laterality of resection, and the severity or duration of preoperative hypercortisolism likely contributed to the differences observed across studies.[39-41]

Regarding perioperative complications, our analysis showed that the PA procedure is associated with an over 40% lower risk of developing complications compared to TA (OR = 0.56; 95% CI, 0.40-0.78). This difference was significantly pronounced in milder complications, particularly those classified as Clavien-Dindo grade I. This may be due to the less-invasive nature of PA, which involves the preservation of adrenal tissue.[42] These findings are in line with previous studies reporting low overall complication rates in minimally invasive adrenal-sparing procedures.[14,43,44] Nevertheless, our study revealed no differences in severe complications between the PA and TA groups, which suggests that while PA may reduce the risk of minor perioperative issues, it does not appear to alter the likelihood of more serious complications.

In terms of intraoperative characteristics, no significant differences were observed regarding operation duration (mean difference = -0.12; 95% CI, -40.37 to 40.14)

and mean blood loss (mean difference = 2.78; 95% CI, -10.33 to 15.89). This finding suggests that, with appropriate surgical expertise, PA does not necessarily result in longer procedures or an increased bleeding risk compared to TA, despite its often more technically demanding nature.[45] The substantial heterogeneity observed in these analyses ($I^2 > 85\%$), however, indicates considerable variation among the included studies, likely due to differences in surgical technique, patient complexity, and reporting methods.

To our knowledge, this is the first systematic review and meta-analysis to comprehensively pool data from studies investigating both partial and total adrenalectomy across a broad spectrum of adrenal pathologies. By utilizing data from 19 articles and more than 3,000 patients, this systematic review and meta-analysis provides a clearer picture of the comparison of partial and total adrenalectomy in terms of outcomes. Furthermore, our subgroup analyses, conducted when adequate information was available, based on tumor pathology and surgical approach, enabled a more detailed interpretation of outcome variations. Another key strength of our study is that a wide range of outcomes was investigated, including oncological outcomes, steroid dependency, and perioperative complications.

However, our study has several limitations. First, although subgroup analyses by pathology, surgical approach, and laterality were conducted, they could not be performed for all outcomes because of limited data in certain subgroups. In some cases, such as recurrence in Cushing's syndrome, only a single study contributed data, making those specific findings less conclusive. Second, the retrospective nature of the majority of the included studies (18 of 19) introduces a potential for selection bias. Finally, the high levels of heterogeneity in some of our key analyses, such as for operative time, blood loss, and functional outcomes, suggest that the results should be interpreted with caution, as other unmeasured variables may be influencing the outcomes.

CONCLUSIONS

PA was associated with higher recurrence risk, particularly in pheochromocytoma, while demonstrating lower perioperative complication rates. In terms of functional outcomes, PA demonstrated better preservation of adrenal function compared with TA, with significantly lower rates of steroid dependency and adrenal insufficiency on pooled analysis. No significant differences were observed for metastasis or mortality. Subgroup analyses did not identify meaningful effect modification by surgical approach or laterality. Overall, PA appears safer in the short term due to fewer perioperative complications and better preservation of adrenal function, whereas TA may provide superior protection against recurrence. Further studies are needed to compare open, laparoscopic, and robotic approaches for both procedures, as well as long-term outcomes in Cushing's and Conn's syndromes.

SUMMARY

Partial adrenalectomy showed a higher recurrence risk, particularly in pheochromocytoma, but was associated with fewer mild perioperative complications.

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Not applicable

CONFLICT OF INTEREST

None declared by the authors.

APPENDIX

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