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Robot-Assisted Partial Nephrectomy Versus Selective Artery Embolization Before Laparoscopic Partial Nephrectomy Versus Laparoscopic Partial Nephrectomy for Renal Angiomyolipoma: A Meta-Analysis

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ADMINISTRATIVE INFORMATION

Support - Robot-Assisted Partial Nephrectomy Versus Selective Artery Embolization Before Laparoscopic Partial Nephrectomy Versus Laparoscopic Partial Nephrectomy for Renal Angiomyolipoma: A Meta-Analysis.

Review Stage at time of this submission - Completed but not published.

Conflicts of interest - None declared.

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Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 17 October 2025 and was last updated on 17 October 2025.

INTRODUCTION

Review question / Objective Population (P):
Patients diagnosed with renal angiomyolipoma (AML) undergoing nephron-sparing surgical management.
Intervention (I):
Either robot-assisted partial nephrectomy (RAPN) or selective arterial embolization prior to laparoscopic partial nephrectomy (SAE+LPN).
Comparator (C):
Conventional laparoscopic partial nephrectomy (LPN) without robotic assistance or preoperative embolization.
Outcomes (O):
Primary outcomes include operative time, warm ischemia time, and intraoperative blood loss.
Secondary outcomes include postoperative renal function (eGFR, serum creatinine), length of hospital stay, and perioperative complications (Clavien–Dindo grade ≥ II).
Exploratory outcomes include cost-minimization and sensitivity analyses of procedural and hospitalization costs.
Study design (S):
Comparative studies (randomized controlled trials, prospective or retrospective cohort studies) reporting at least one of the prespecified outcomes.
Review objective:
To systematically evaluate and compare the perioperative outcomes and cost profiles of robot-assisted partial nephrectomy (RAPN) and selective arterial embolization prior to laparoscopic partial nephrectomy (SAE+LPN) versus standard laparoscopic partial nephrectomy (LPN) in patients with renal angiomyolipoma (AML), aiming to

identify optimal minimally invasive strategies for individualized surgical planning.

Rationale The optimal surgical strategy for renal angiomyolipoma (AML) remains controversial. Although laparoscopic partial nephrectomy (LPN) is a standard nephron-sparing procedure, it can be technically demanding in large or highly vascular AMLs. Robot-assisted partial nephrectomy (RAPN) has been introduced to improve surgical precision and reduce ischemic injury, while selective arterial embolization before LPN (SAE+LPN) may decrease intraoperative bleeding and operative time. However, the comparative perioperative and functional benefits of these minimally invasive approaches over conventional LPN have not been clearly established. A systematic review and meta-analysis is therefore warranted to comprehensively evaluate their relative efficacy, safety, and cost implications in AML management.

Condition being studied Renal angiomyolipoma (AML) is a benign renal tumor composed of blood vessels, smooth muscle, and adipose tissue. Although often asymptomatic, large or symptomatic AMLs can cause flank pain, hematuria, or spontaneous retroperitoneal hemorrhage, sometimes leading to life-threatening bleeding. Surgical or interventional treatment is recommended for tumors larger than 4 cm or with a high risk of rupture. Current minimally invasive options include laparoscopic partial nephrectomy (LPN), robot-assisted partial nephrectomy (RAPN), and selective arterial embolization (SAE)—alone or in combination—to preserve renal function and reduce perioperative morbidity.

METHODS

Search strategy A comprehensive search was performed in the following electronic databases: PubMed, Embase, Web of Science, Cochrane Library, Scopus, and China National Knowledge Infrastructure (CNKI) from inception to September 25, 2025, with no language restrictions.

The search strategy combined controlled vocabulary (MeSH/Emtree) and free-text terms related to renal angiomyolipoma and the target interventions.

Representative PubMed search string:

((Angiomyolipoma[Mesh] OR angiomyolipoma* OR “renal AML” OR “renal angiomyolipoma” OR “kidney angiomyolipoma”) AND (robot-assisted OR robotic OR RAPN OR laparoscop* OR LPN))
OR
((Angiomyolipoma[Mesh] OR angiomyolipoma* OR “renal AML” OR “renal angiomyolipoma” OR “kidney angiomyolipoma”) AND (“selective arterial embolization” OR “superselective arterial embolization” OR “renal artery embolization” OR SAE) AND (“partial nephrectomy”[Mesh] OR “partial nephrectom*” OR “nephron-sparing surgery” OR LPN OR laparoscop*))

Embase Search Strategy: (‘angiomyolipoma’/exp OR angiomyolipoma* OR ‘renal aml’ OR ‘renal angiomyolipoma’ OR ‘kidney angiomyolipoma’) AND ((robot-assisted OR robotic OR ‘da vinci’ OR rapn OR laparoscop* OR LPN) OR (‘selective arterial embolization’ OR ‘superselective arterial embolization’ OR ‘renal artery embolization’ OR SAE))

Cochrane Library Search Strategy: (angiomyolipoma OR “renal AML” OR “renal angiomyolipoma” OR “kidney angiomyolipoma”) in Title Abstract Keyword AND (robot-assisted OR robotic OR “da Vinci” OR RAPN OR laparoscop* OR LPN) OR ((angiomyolipoma OR “renal AML” OR “renal angiomyolipoma” OR “kidney angiomyolipoma”) AND (“selective arterial embolization” OR “superselective arterial embolization” OR “renal artery embolization” OR SAE) AND (“partial nephrectomy” OR “partial nephrectom*” OR “nephron-sparing surgery” OR LPN OR laparoscop*))

Web of Science Search Strategy: TS = ((angiomyolipoma* OR “renal AML” OR “renal angiomyolipoma” OR “kidney angiomyolipoma”) AND (robot-assisted OR robotic OR “da Vinci” OR RAPN OR laparoscop* OR LPN)) OR TS = ((angiomyolipoma* OR “renal AML” OR “renal angiomyolipoma” OR “kidney angiomyolipoma”) AND (“selective arterial embolization” OR “superselective arterial embolization” OR “renal artery embolization” OR SAE) AND (“partial nephrectomy” OR “partial nephrectom*” OR “nephron-sparing surgery” OR LPN OR laparoscop*))

Scopus Search Strategy: ("renal angiomyolipoma" OR "renal AML" OR "kidney angiomyolipoma")
AND ("partial nephrectomy" OR "nephron-sparing surgery" OR "PN")
AND ("robot-assisted" OR "robotic" OR "laparoscopic" OR "minimally invasive")
AND ("selective arterial embolization" OR "super-selective embolization" OR "SAE" OR "transcatheter arterial embolization" OR "TAE")
AND (outcome* OR complication* OR "warm ischemia time" OR "operative time" OR "estimated blood loss" OR "renal function" OR "hospital stay")

China National Knowledge Infrastructure Search Strategy: (“肾血管平滑肌脂肪瘤” OR “肾AML”) AND (“机器人辅助部分肾切除术” OR “机器人部分

肾切除术" OR "RAPN" OR "腹腔镜部分肾切除术" OR "LPN" OR "选择性动脉栓塞" OR "SAE").

Participant or population This review focuses on adult patients diagnosed with renal angiomyolipoma (AML), a benign renal tumor composed of blood vessels, smooth muscle, and adipose tissue. The included population comprises patients who underwent nephron-sparing surgical procedures indicated for large (≥4 cm) or symptomatic AMLs associated with flank pain, hematuria, or hemorrhagic risk. Both sporadic and tuberous sclerosis–associated AML cases were eligible if analyzed separately or if data were extractable for AML-only cohorts.

Eligible studies enrolled patients treated with one of the following minimally invasive surgical approaches:

Robot-assisted partial nephrectomy (RAPN) – performed using a robotic surgical system to enhance precision, dexterity, and visualization;

Selective arterial embolization prior to laparoscopic partial nephrectomy (SAE+LPN) – an interventional approach combining preoperative tumor devascularization with laparoscopic resection;

Conventional laparoscopic partial nephrectomy (LPN) – serving as the primary comparator for both interventions.

Participants were required to have undergone partial nephrectomy with curative intent, with available perioperative outcome data such as operative time, warm ischemia time, intraoperative blood loss, postoperative renal function, hospital stay, or complication rates.

Exclusion criteria were:

Patients with malignant renal tumors or mixed renal neoplasm cohorts where AML-specific data could not be extracted;

Studies involving open surgery, embolization alone, or ablative therapies without partial nephrectomy;

Pediatric-only populations or case reports/series without a comparative arm;

Duplicated datasets or overlapping patient cohorts, in which case the most complete or latest study was retained.

This population definition ensures the review captures clinically comparable adult AML patients undergoing minimally invasive, nephron-sparing surgery, facilitating valid comparison of perioperative outcomes among RAPN, SAE+LPN, and standard LPN.

Intervention Two types of minimally invasive interventions were evaluated in this review, both representing advanced nephron-sparing strategies for the surgical management of renal angiomyolipoma (AML):

Robot-Assisted Partial Nephrectomy (RAPN):

RAPN is a robotic platform–based technique designed to enhance surgical precision, dexterity, and three-dimensional visualization during partial nephrectomy. Using articulated robotic instruments under surgeon control, RAPN facilitates meticulous tumor excision and renorrhaphy with minimal warm ischemia time and reduced parenchymal trauma. It is intended to improve perioperative safety and preserve postoperative renal function compared with conventional laparoscopic approaches.

Selective Arterial Embolization Prior to Laparoscopic Partial Nephrectomy (SAE+LPN):

SAE+LPN is a combined interventional and surgical approach in which the tumor's feeding arteries are selectively embolized before laparoscopic partial nephrectomy. Preoperative embolization decreases intraoperative vascularity, thereby reducing blood loss, shortening operative time, and improving visualization during tumor resection. This strategy aims to enhance surgical safety and efficiency, particularly in large or hypervascular AMLs.

Both RAPN and SAE+LPN were evaluated against standard laparoscopic partial nephrectomy (LPN), which served as the reference technique. The review systematically compared their perioperative outcomes (operative time, warm ischemia time, blood loss, hospital stay, complications, renal function) and economic profiles, to determine whether these minimally invasive interventions offer measurable clinical or cost-effectiveness advantages in AML management.

Comparator The comparator intervention in this review is standard laparoscopic partial nephrectomy (LPN) performed without robotic assistance or preoperative selective arterial embolization.

LPN represents the conventional minimally invasive nephron-sparing technique for the management of renal angiomyolipoma (AML). It involves laparoscopic tumor excision and renal reconstruction under warm ischemia, using standard laparoscopic instruments and two-dimensional visualization.

As the established standard of care in many centers, LPN serves as the reference procedure against which the two advanced minimally invasive strategies—robot-assisted partial nephrectomy (RAPN) and selective arterial embolization prior to laparoscopic partial nephrectomy (SAE+LPN)—were compared.

Comparisons were made in terms of perioperative parameters (operative time, warm ischemia time, blood loss, hospital stay, complications, postoperative renal function) and economic outcomes, to determine whether the newer

approaches provide measurable clinical or cost-effectiveness advantages over conventional LPN.

Study designs to be included Only observational comparative studies were included, encompassing both prospective and retrospective cohort designs that directly compared RAPN or SAE+LPN with standard LPN in patients with renal angiomyolipoma. Studies using propensity score matching or multivariable adjustment were eligible. Non-comparative studies, randomized trials, case reports, conference abstracts, and reviews were excluded to ensure consistent methodological quality across included evidence.

Eligibility criteria Inclusion criteria:
Studies involving adult patients diagnosed with renal angiomyolipoma (AML) undergoing partial nephrectomy (robot-assisted, laparoscopic, or SAE-assisted laparoscopic).
Comparative observational studies evaluating either RAPN vs LPN or SAE+LPN vs LPN.
Studies reporting at least one perioperative or postoperative outcome of interest, including operative time, warm ischemia time, intraoperative blood loss, renal function (eGFR or serum creatinine), hospital stay, or complications.
Articles published in peer-reviewed journals with full-text availability and extractable numerical data suitable for meta-analysis.
Exclusion criteria:
Non-comparative studies (e.g., single-arm series, case reports).
Studies including renal malignancies or mixed tumor cohorts without extractable AML-only data.
Studies not involving partial nephrectomy (e.g., embolization alone, ablation, or open surgery only).
Pediatric-only populations or duplicated datasets from overlapping cohorts.
Conference abstracts, letters, editorials, and animal or in vitro experiments lacking analyzable outcomes.

Information sources A comprehensive literature search was conducted using six major electronic databases: PubMed, Embase, Web of Science, Cochrane Library, Scopus, and China National Knowledge Infrastructure (CNKI), from their inception to September 25, 2025, without language restrictions.
In addition, reference lists of all included studies and relevant reviews were manually screened to identify additional eligible publications. When necessary, study authors were contacted via email to obtain missing or unclear data required for meta-analysis.
No formal search of clinical trial registries or grey literature databases was performed, as all included evidence originated from published observational comparative studies with extractable perioperative outcomes.

Main outcome(s)
The primary outcomes of this review were key perioperative parameters:
Operative time (minutes)
Warm ischemia time (minutes)
Intraoperative blood loss (milliliters)
The secondary outcomes included:
Postoperative renal function, measured as estimated glomerular filtration rate (eGFR, mL/min/1.73 m^2) and serum creatinine (mg/dL), assessed at discharge or within 3 months postoperatively;
Length of hospital stay (days);
Perioperative complications, defined as any event within 30 days after surgery and graded according to the Clavien–Dindo classification (grade ≥ II).
An exploratory outcome was economic evaluation, expressed as direct medical cost differences (USD 2023) covering robotic amortization, embolization costs, operating time, and hospitalization, analyzed through a structured cost-minimization and one-way sensitivity framework (±20%).
Effect sizes were synthesized as mean differences (MD) for continuous outcomes and odds ratios (OR) for binary outcomes, both with 95% confidence intervals (CI) under a random-effects model (REML + Knapp–Hartung adjustments).

Additional outcome(s) Additional and exploratory outcomes were assessed to provide a deeper understanding of heterogeneity, effect modification, and economic impact:
Exploratory meta-regression analyses were performed to examine potential moderators influencing perioperative outcomes, including tumor size, R.E.N.A.L. nephrometry score, baseline eGFR, publication year, and geographic region. Regression coefficients (β) were interpreted as the marginal change in the pooled effect per unit increase in the moderator.
Sensitivity analyses included:
Leave-one-out influence diagnostics;
Exclusion of high–risk-of-bias studies;
Alternative model estimations (DerSimonian–Laird ± Knapp–Hartung).
Economic analysis:
A structured cost-minimization analysis was conducted, estimating procedure-specific and hospitalization costs (in 2023 USD) with deterministic one-way sensitivity testing (±20%) and scenario analyses to assess cost robustness.

Data management All search records retrieved from electronic databases were imported into EndNote X9 for reference management and

duplicate removal. Two reviewers independently screened titles, abstracts, and full texts, with discrepancies resolved through discussion and arbitration by a third reviewer.

A standardized data extraction form was developed in Microsoft Excel to collect study characteristics (author, year, country, design, sample size, patient demographics, tumor features, surgical approach) and outcome data (means, standard deviations, event counts).

When outcomes were reported as median with interquartile range or range, means and standard deviations were estimated using established statistical conversion formulas. All extracted data were double-checked for accuracy before pooling.

Statistical analyses, including meta-analyses, sensitivity analyses, and meta-regressions, were performed using R software (version 4.5.1) with the metafor and meta packages. Summary tables, figures, and supplementary materials were stored securely with version control.

Quality assessment / Risk of bias analysis Given that all included studies were observational comparative studies, methodological quality and risk of bias were assessed using the Newcastle–Ottawa Scale (NOS). This tool evaluates three domains:

Selection of study groups (maximum 4 stars),

Comparability of groups (maximum 2 stars), and

Ascertainment of outcomes (maximum 3 stars).

Two reviewers independently performed the NOS assessment after a calibration exercise, with disagreements resolved through discussion and arbitration by a third reviewer.

For AML-specific studies, comparability was judged based on adjustment for key confounders —age, tumor size, R.E.N.A.L. score, and baseline renal function. Studies scoring 7–9 stars were considered low risk of bias, 4–6 stars moderate risk, and ≤3 stars high risk.

Strategy of data synthesis All quantitative syntheses were performed in accordance with the Cochrane Handbook for Systematic Reviews of Interventions. Continuous outcomes were pooled as mean differences (MD) with 95% confidence intervals (CI), and dichotomous outcomes were pooled as odds ratios (OR) with 95% CIs.

A random-effects model was used by default, with Restricted Maximum Likelihood (REML) estimation of between-study variance (τ^2) and Knapp–Hartung (KH) adjustments for confidence intervals and p-values. Heterogeneity was assessed using τ^2 and I^2 statistics, and 95% prediction intervals (PI) were reported where feasible.

Sensitivity analyses included switching to DerSimonian–Laird models (with/without KH adjustment), excluding high-risk studies, and conducting leave-one-out diagnostics.

For rare events, a Haldane–Anscombe 0.5 continuity correction was applied when single-arm zero events occurred; double-zero studies were excluded a priori.

Exploratory meta-regression analyses (REML + KH) were performed to examine potential moderators such as tumor size, R.E.N.A.L. score, and baseline eGFR. All analyses were conducted in R 4.5.1 using the metafor (v4.8-0) and meta (v8.2-1) packages.

Subgroup analysis Predefined subgroup analyses were performed to explore potential sources of heterogeneity and clinical effect modification. Subgroups were based on clinically relevant and methodological factors, including:

Tumor size (e.g., <4 cm vs ≥4 cm, or mean tumor diameter per study), R.E.N.A.L. nephrometry score (reflecting anatomical complexity), Baseline renal function (measured by preoperative eGFR), Publication year (before vs after 2020), and Geographic region (Asia vs non-Asia).

Each subgroup analysis used a random-effects model (REML + Knapp–Hartung) consistent with the primary synthesis.

Exploratory meta-regression was also performed when ≥3 studies were available per outcome to quantify the influence of continuous moderators (e.g., slope in minutes per 1-cm increase in tumor size). These analyses were considered hypothesis-generating and interpreted descriptively due to limited study numbers.

Sensitivity analysis Multiple sensitivity analyses were conducted to assess the robustness and stability of pooled estimates.

Leave-one-out analysis: Each study was sequentially excluded to evaluate its influence on the overall pooled effect size.

Model comparison: Results obtained using the random-effects model (REML + Knapp–Hartung adjustment) were compared with those from the DerSimonian–Laird model (with and without KH adjustment).

Risk-of-bias exclusion: Analyses were repeated after excluding studies rated as high risk of bias on the Newcastle–Ottawa Scale.

Continuity correction sensitivity: For rare binary outcomes, a Haldane–Anscombe 0.5 correction was applied; results were checked by omitting double-zero studies.

Language restriction No language restrictions were applied during the literature search. Studies published in any language were considered

eligible, provided that sufficient data could be extracted for quantitative or qualitative synthesis.

Country(ies) involved China.

Keywords Renal angiomyolipoma; Robot-assisted partial nephrectomy; Laparoscopic partial nephrectomy; Selective arterial embolization; Minimally invasive surgery; Systematic review; Meta-analysis; Perioperative outcomes; Nephron-sparing.

Dissemination plans The results of this systematic review and meta-analysis will be submitted for publication in a peer-reviewed international journal in the fields of urology or minimally invasive surgery. The findings will also be presented at relevant academic conferences to inform clinical practice and future research on the surgical management of renal angiomyolipoma (AML).
Upon publication, the complete dataset, analytic code, and supplementary materials will be made publicly available through institutional repositories or journal supplementary files, ensuring transparency and reproducibility of the research.

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