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Yang Zhao
Chinese PLA General Hospital
Ce Han
Chinese PLA General Hospital
Lifei Ma
Beijing Jingdu Children's Hospital Beijing
Tian Tao
Chinese PLA General Hospital
Yuandong Tao
Chinese PLA General Hospital
Pin Li
Chinese PLA General Hospital
Xiaoguang Zhou
Chinese PLA General Hospital
Huixia Zhou
huixia999990163.com
Chinese PLA General Hospital

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Body-tumor ratio as a predictor of intraoperative complications after robot-assisted laparoscopic pediatric renal tumor resection

Yang Zhao [a,b,1], Ce Han [a, 1] , Lifei Ma [c,1] , Tian Tao [a] , Yuandong Tao [a], Pin Li [a], Xiaoguang Zhou [a], Huixia Zhou [a, b ,*]

a Senior Department of Pediatrics, Chinese PLA General Hospital, Beijing, China

b Medical School of Chinese PLA, Beijing 100010, China

c Beijing Jingdu Children's Hospital， Beijing, China

*Corresponding author: Huixia Zhou (huixia99999@163.com) ;

1These authors contributed equally to this work.

Abstract

Objective To identify risk factors for intraoperative complications during robot-assisted laparoscopic nephrectomy (RALN) for pediatric renal tumors, and to evaluate whether body size-adjusted tumor ratios predict these complications better than absolute tumor diameter alone. We also sought to determine optimal cutoff values for these ratios.

Methods We retrospectively reviewed 128 children with renal tumors who underwent RALN at a single center between January 2016 and December 2024. There were 75 boys and 53 girls, with a median age of 46 months (range 6 to 95 months). We recorded age, height, weight, and abdominal circumference, together with maximum tumor diameter (MTD). From these we calculated the height-to-tumor diameter ratio (HTD), abdominal circumference-to-tumor diameter ratio (ACD), weight-to-tumor diameter ratio (WTD), and tumor-to-abdominal cavity volume ratio (TAVR). The primary outcome was intraoperative complication, defined as major hemorrhage, tumor rupture, renal pedicle or major vessel injury, injury to adjacent organs, or conversion to open surgery. Receiver operating characteristic (ROC) analysis determined cutoff values, and multivariable logistic regression identified independent predictors.

Results Intraoperative complications occurred in 25 of 128 patients (19.5%). The complication group had a significantly larger MTD (8.7 cm vs 6.4 cm) and significantly lower HTD (10.8 vs 15.5) and ACD (5.2 vs 7.3) than the group without complications (all $P < 0.05$). ACD had the largest area under the curve (AUC 0.771; cutoff 5.57,

sensitivity 60.0%, specificity 84.5%), followed by HTD (AUC 0.761; cutoff 11.99, sensitivity 64.0%, specificity 79.6%); both outperformed MTD (AUC 0.752) and age (AUC 0.609). In multivariable analysis, ln(HTD) (OR 0.052, 95% CI 0.010 to 0.358, P = 0.003) and ln(ACD) (OR 0.042, 95% CI 0.010 to 0.310, P = 0.002) were independent protective factors.

Conclusion Body size-adjusted tumor ratios predict intraoperative complications during RALN more accurately than MTD alone. We suggest HTD of 12.0 and ACD of 5.6 as general cutoff values for preoperative risk assessment, with an HTD cutoff of 10.3 for infants 24 months of age or younger.

Keywords Robotic surgery; Nephrectomy; Child; Kidney neoplasm; Risk factors; Intraoperative complications; ROC curve

Introduction

Wilms tumor and other primary renal tumors are common solid tumors in pediatric urology. As robot-assisted laparoscopy has gained ground in pediatric surgery, robot-assisted laparoscopic nephrectomy (RALN) has been used more often in children with renal tumors because it offers precise manipulation, magnified visualization, and high instrument dexterity. For selected children, it provides a minimally invasive option. However, the pediatric abdominal cavity is small, children vary greatly in body habitus, and tumor size differs widely. Minimally invasive surgery still carries risks of major intraoperative hemorrhage, tumor rupture, injury to adjacent organs, and conversion to open surgery. Events such as tumor rupture and major hemorrhage not only threaten surgical safety but may also worsen oncologic outcomes.

At present, case selection for RALN relies mainly on absolute tumor size, and maximum tumor diameter (MTD) in particular. Protocols such as SIOP-RTSG have also used absolute tumor size as a key criterion for minimally invasive surgery. In clinical practice, however, children of the same absolute tumor size who are younger and smaller are harder to operate on and carry a higher complication risk than older, larger children. Absolute diameter alone does not reflect how much of the abdominal cavity a tumor actually occupies, and it cannot support individualized risk prediction. There is therefore a need for a simple risk index that incorporates the child's own body size and can be used

for preoperative stratification, surgical planning, doctor-family communication, and timing of neoadjuvant chemotherapy. This study aimed to identify risk factors for intraoperative complications during RALN, to evaluate the predictive value of body size-adjusted tumor ratios, and to provide a new reference for preoperative risk assessment in minimally invasive renal tumor surgery in children.

Materials and Methods

Patients and eligibility criteria

We retrospectively collected clinical data from children with renal tumors who underwent RALN in our pediatric surgery department between January 2016 and December 2024. Inclusion criteria were: (1) age of 14 years or younger; (2) a primary solid or mixed cystic-solid renal mass confirmed by contrast-enhanced CT or MRI before surgery; and (3) radical nephrectomy or partial nephrectomy performed on the same robotic platform (da Vinci Si or Xi). Exclusion criteria were: (1) bilateral renal tumors; (2) preoperative imaging showing venous tumor thrombus, tumor rupture, distant metastasis, or invasion of adjacent organs; (3) concurrent resection of other organs; and (4) incomplete clinical data. The study was approved by the hospital ethics committee (approval number BJJQZYY-2025-0104), and the requirement for informed consent was waived.

Measurement and definitions

Before surgery, a dedicated staff member measured height (cm), weight (kg), and abdominal circumference (cm) according to a uniform standard; abdominal circumference was taken as the maximum girth at the level of the umbilicus. MTD was the largest of the three orthogonal diameters measured on contrast-enhanced CT in the axial, coronal, and sagittal planes. We then calculated the following ratios: HTD = height/MTD, ACD = abdominal circumference/MTD, and WTD = weight/MTD. Tumor volume was estimated with the ellipsoid formula $V = \pi/6 \times a \times b \times c$, and abdominal cavity volume was approximated as $\pi \times (\text{abdominal circumference}/2\pi)^2 \times \text{height} \times 0.5$. The ratio of the two yielded TAVR.

Surgical procedure

All procedures used a transperitoneal approach. After general anesthesia, the child was placed in a 60-degree lateral position with the affected side up. A camera port was placed at the umbilicus, and two to three 8-mm robotic working ports plus one 5-mm assistant port were inserted. The renal pedicle was exposed first; the renal artery and vein were divided with Hem-o-lok clips, and the ureter was then divided. The kidney and tumor were mobilized and removed intact in a retrieval bag through a small umbilical incision. Lymph node sampling at the renal hilum and retroperitoneum was performed routinely. Partial nephrectomy was reserved for small exophytic tumors confined to one pole.

Outcome measures

The primary outcome was intraoperative complication, defined as any of the following: (1) major hemorrhage (estimated blood loss of at least 10% of the child's estimated blood volume, or requiring intraoperative transfusion); (2) tumor rupture; (3) renal pedicle or major vessel injury; (4) injury to adjacent organs (bowel, pancreas, spleen, diaphragm, or others); or (5) conversion to open surgery. Secondary outcomes included operative time, intraoperative blood loss, and postoperative length of stay.

Statistical analysis

SPSS 26.0 was used for analysis. After testing for normality, continuous variables were expressed as median (Q1, Q3) and compared with the Mann-Whitney U test. Categorical variables were expressed as counts (percentages) and compared with the chi-square test or Fisher exact test. ROC analysis was used to assess the ability of each index to predict intraoperative complications, and cutoff values were chosen by maximizing the Youden index, with sensitivity, specificity, and AUC calculated. Variables with $P < 0.10$ on univariable analysis, together with clinically relevant variables, were entered into multivariable logistic regression models. Ratio indices were log-transformed before entering the model, and odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. A two-sided $P < 0.05$ was considered statistically significant.

Results

Baseline characteristics

A total of 128 children were included: 75 boys (58.6%) and 53 girls (41.4%), with a median age of 46 months (range 6 to 95 months). The tumor was on the right in 68 cases and on the left in 60. Postoperative pathology showed Wilms tumor in 92 (71.9%), ganglioneuroblastoma in 22 (17.2%), renal cell carcinoma in 8 (6.3%), and mesoblastic nephroma in 6 (4.7%). Neoadjuvant chemotherapy had been given in 87 cases (68.0%). The median MTD was 6.85 cm (range 2.0 to 12.0), median HTD was 14.45, and median ACD was 6.99. The median operative time was 257 min (range 161 to 358), and median blood loss was 100 mL (range 6 to 264).

Intraoperative complications occurred in 25 patients (19.5%), including major hemorrhage in 11 (8.6%), conversion to open surgery in 7 (5.5%), tumor rupture in 4 (3.1%), bowel injury in 2 (1.6%), and renal pedicle vessel injury in 1 (0.8%). Two patients (1.6%) required intraoperative transfusion. There were no deaths intraoperatively or within 30 days after surgery.

Comparison between patients with and without complications

Continuous variables in the two groups are compared in Table 1 and Figure 2. MTD was significantly larger in the complication group than in the group without complications, whereas HTD, ACD, WTD, and TAVR were all significantly lower. Operative time and intraoperative blood loss were also significantly greater in the complication group. Age, height, weight, and abdominal circumference did not differ significantly between the groups. Sex, tumor laterality, pathologic type, and use of neoadjuvant chemotherapy were also similarly distributed (all $P > 0.05$).

Table 1. Comparison of continuous variables between patients with and without intraoperative complications [median (Q1, Q3)]

Variable	Complication (n = 25)	No complication (n = 103)	P value
Age (months)	40.00 (26.00–51.00)	46.00 (36.50–58.50)	0.095
Height (cm)	95.50 (89.90–103.70)	99.90 (93.15–105.50)	0.089
Weight (kg)	14.60 (12.10–17.70)	16.20 (14.45–18.70)	0.057
Abdominal circumference (cm)	45.40 (42.10–48.70)	47.20 (44.25–50.80)	0.102

MTD (cm)	8.70 (7.20–10.00)	6.40 (5.10–7.60)	<0.001
HTD	10.83 (9.38–13.54)	15.54 (12.59–19.68)	<0.001
ACD	5.19 (4.62–6.62)	7.32 (6.05–9.27)	<0.001
WTD	1.74 (1.38–2.00)	2.44 (1.96–3.27)	<0.001
TAVR	0.04 (0.02–0.06)	0.01 (0.01–0.02)	<0.001
Operative time (min)	277.00 (261.00–303.00)	248.00 (225.00–272.00)	<0.001
Blood loss (mL)	122.00 (88.00–144.00)	98.00 (74.50–120.00)	0.031

ROC analysis and cutoff determination

ROC results are shown in Table 2 and Figure 1. All body size-adjusted tumor ratios had a larger AUC than MTD and age, with ACD the largest (0.771) and HTD the next (0.761), indicating that the ratio indices discriminated intraoperative complications better than tumor diameter alone. Cutoff values chosen by maximizing the Youden index were 11.99 (about 12.0) for HTD, 5.57 (about 5.6) for ACD, 2.07 for WTD, 8.3 cm for MTD, and 0.029 for TAVR.

Table 2. ROC analysis of each index for predicting intraoperative complications

Index	AUC	Cutoff	Sensitivity	Specificity	Youden index
HTD	0.761	11.99	0.640	0.796	0.436
ACD	0.771	5.57	0.600	0.845	0.445
WTD	0.762	2.07	0.800	0.689	0.489
MTD	0.752	8.30	0.600	0.845	0.445
TAVR	0.772	0.03	0.600	0.845	0.445
Age	0.609	40.00	0.520	0.689	0.209

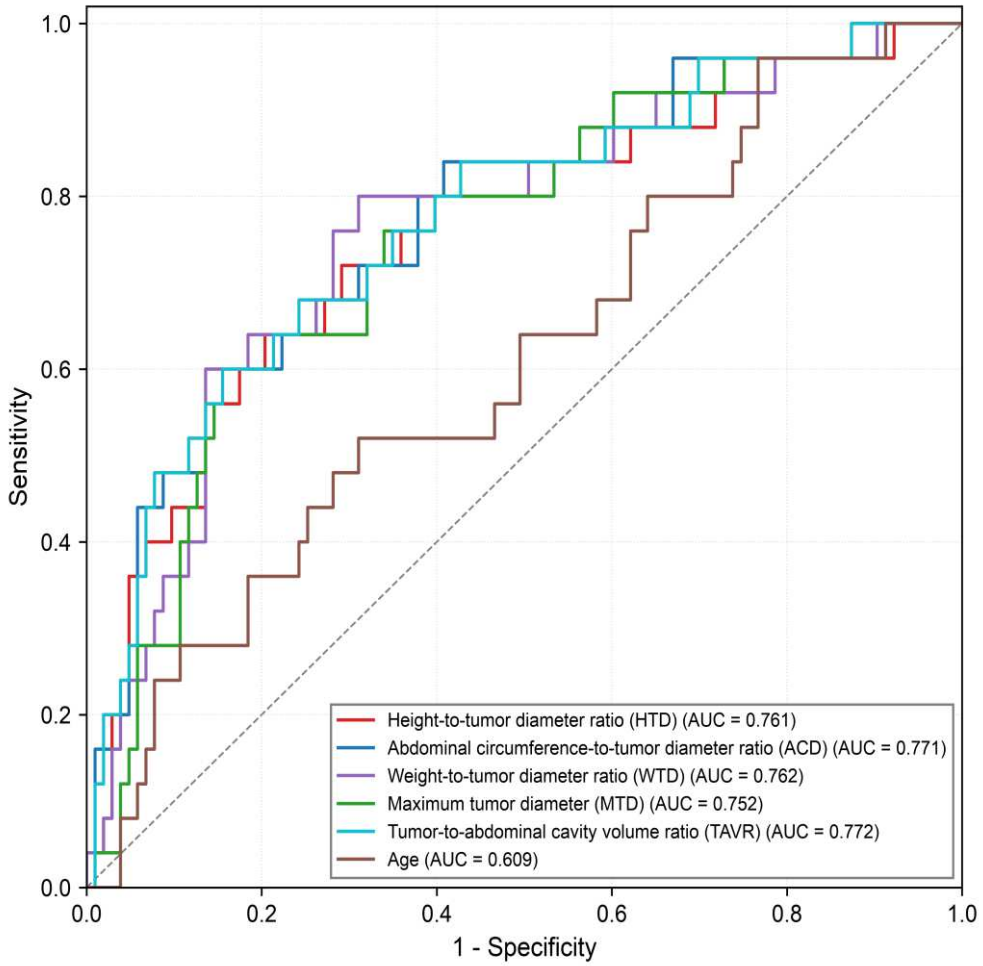

Figure 1. Receiver operating characteristic curves of body size-adjusted tumor ratios, MTD, and age for predicting intraoperative complications.

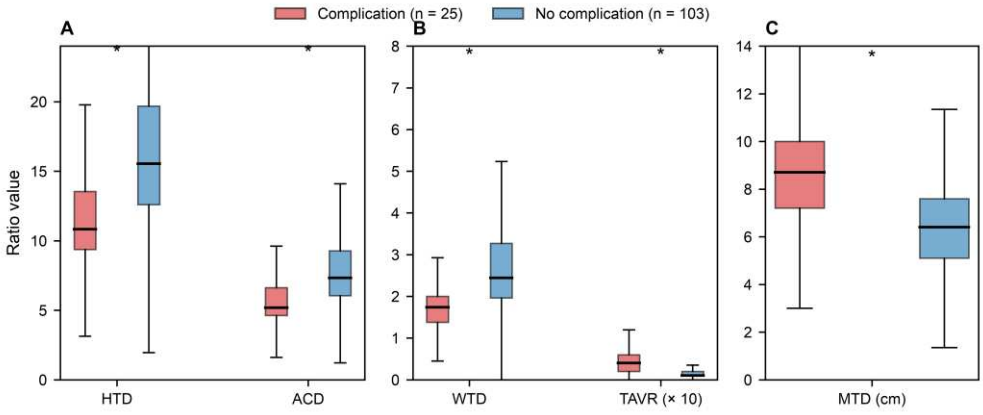

Figure 2. Comparison of HTD, ACD, WTD, TAVR, and MTD between patients with and without intraoperative complications. Boxes show the median and interquartile range; *P < 0.05.

Complication rates after grouping by cutoff

Complication rates after grouping by cutoff are shown in Table 3 and Figure 3. Patients with HTD < 11.99, ACD < 5.57, MTD ≥ 8.3 cm, or TAVR ≥ 0.029 all had significantly higher complication rates than their reference groups (all P < 0.001), with ORs of 6.94, 8.16, 7.08, and 7.59, respectively.

Table 3. Intraoperative complication rates after grouping by cutoff

Index (cutoff)	High-risk group	Low-risk group	OR	P value
HTD < 11.99	16/37 (43.2%)	9/91 (9.9%)	6.94	<0.001
ACD < 5.57	15/31 (48.4%)	10/97 (10.3%)	8.16	<0.001
MTD ≥ 8.3 cm	15/33 (45.5%)	10/95 (10.5%)	7.08	<0.001
TAVR ≥ 0.029	15/32 (46.9%)	10/96 (10.4%)	7.59	<0.001

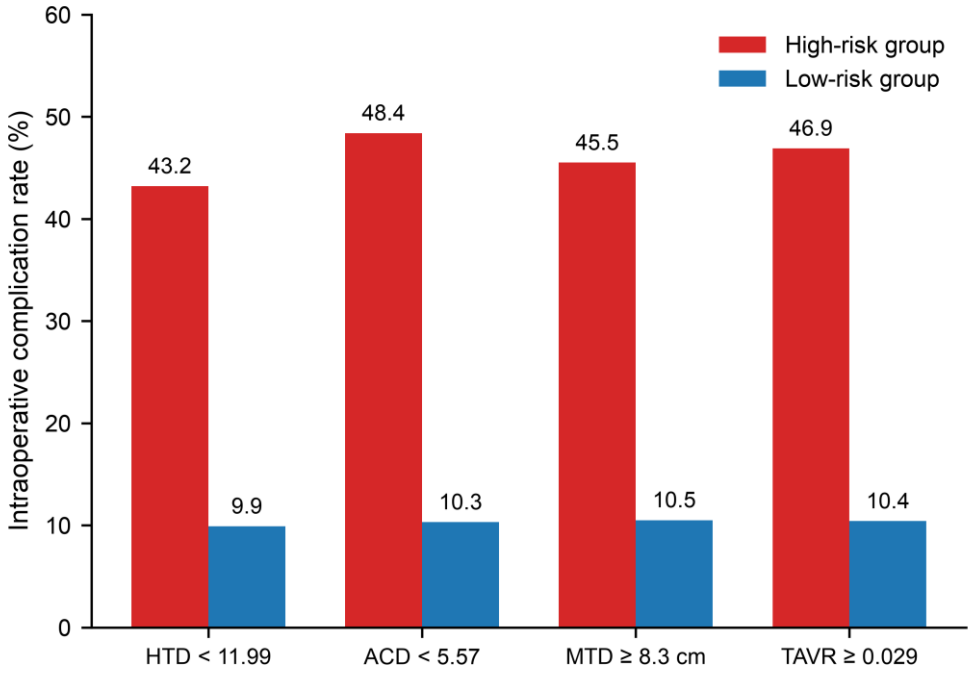

Figure 3. Intraoperative complication rates in high-risk and low-risk groups defined by each cutoff.

Age subgroup analysis

Because body habitus differs greatly across ages, we performed a subgroup analysis using 24 months as the threshold. In the subgroup aged 24 months or younger (n = 15),

HTD had an AUC of 0.704 and a cutoff of 10.33; in the subgroup older than 24 months (n = 113), HTD had an AUC of 0.739 and a cutoff of 14.44. The differing cutoffs suggest that the effect of relative tumor burden on surgical difficulty changes with age.

Multivariable logistic regression

ln(HTD) (or ln(ACD)), age, sex, and neoadjuvant chemotherapy were entered into multivariable logistic regression models (Table 4, Figure 4). In model 1, ln(HTD) was an independent protective factor for intraoperative complications (OR 0.052, 95% CI 0.010 to 0.358, P = 0.003), whereas age, sex, and neoadjuvant chemotherapy were not significant. In model 2, ln(ACD) was likewise an independent protective factor (OR 0.042, 95% CI 0.010 to 0.310, P = 0.002).

Table 4. Multivariable logistic regression of risk factors for intraoperative complications (Model 1)

Variable	β	OR	95% CI	P value
ln(HTD)	−2.951	0.052	0.008–0.360	0.003
Age	−0.003	0.997	0.969–1.026	0.847
Male sex	0.085	1.089	0.405–2.930	0.866
Neoadjuvant chemotherapy	−0.324	0.723	0.266–1.970	0.526

Note: In the model with ln(ACD), ln(ACD) (OR 0.042, 95% CI 0.010–0.310, P = 0.002) was an independent protective factor; age, sex, and neoadjuvant chemotherapy were not significant (all P > 0.05).

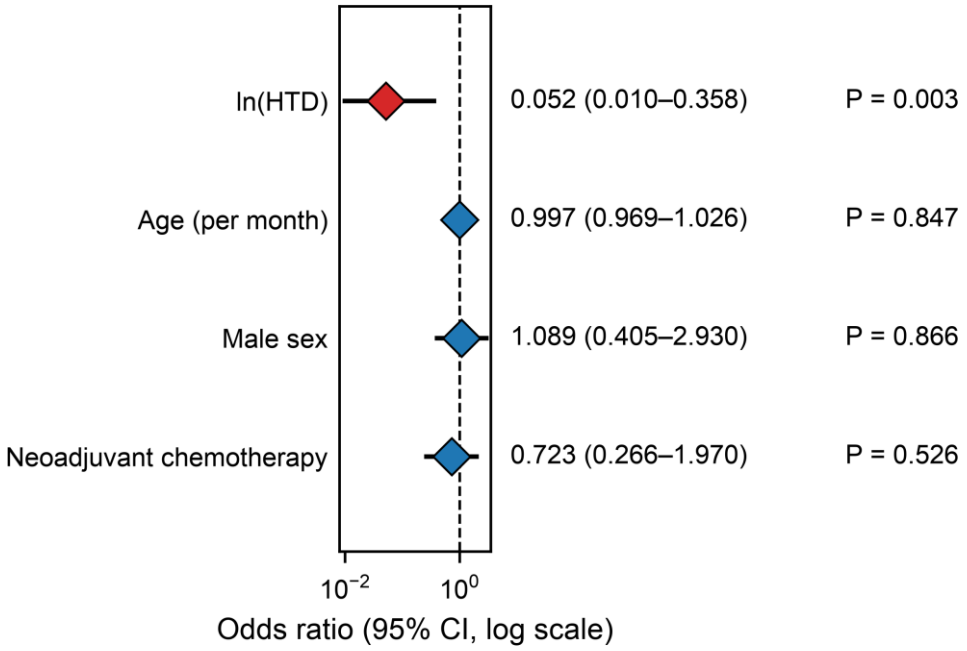

Figure 4. Forest plot of multivariable logistic regression for intraoperative complications (Model 1). Diamonds indicate odds ratios; horizontal lines indicate 95% confidence intervals.

Discussion

In this single-center series of 128 children undergoing RALN, the intraoperative complication rate was 19.5% and the conversion rate was 5.5%. These figures are broadly consistent with the pooled estimates reported by Alansari and colleagues (conversion 6.3%, renal vein injury 2.5%) and with the 5% conversion rate recently reported by Pierucci and colleagues, which suggests that our cohort is representative rather than a highly selected series. My most immediate observation in analyzing the data was that the body size-adjusted ratios HTD and ACD discriminated intraoperative complications better (AUC 0.761 to 0.771) than MTD (AUC 0.752) or age (AUC 0.609), and that they remained independent protective factors after adjustment for age, sex, and neoadjuvant chemotherapy. What struck me further was that age, height, weight, and abdominal circumference did not differ significantly between the complication and non-complication groups, whereas the ratio indices differed markedly. This suggests that the determinant of risk is not the child's absolute body size but the tumor burden relative to that body size. The age subgroup analysis reinforces this point: the HTD cutoff was 10.33 in children 24 months or younger and 14.44 in older children, which explains at a data

level why tumors of the same diameter carry different risks in different children. Taken together, I conclude that what determines the difficulty of RALN is not the absolute size of the tumor but its geometric occupancy relative to the child's body size. This conclusion complements, rather than replaces, current selection criteria based on absolute diameter. Absolute diameter answers how large the tumor is; the ratio index answers how large the tumor is for this particular operation. These are two different questions.

I believe the ratio indices outperform absolute diameter, and the underlying reasons can be understood from three interrelated perspectives: geometry, anatomy, and hemodynamics.

From a geometric standpoint, the impact of a tumor on the operation depends on its volume relative to the available working space, not on a single linear dimension. Tumor volume scales with the cube of MTD, and the effective working space of the abdominal cavity scales roughly with the cube of the linear dimension of the cavity. The tumor-to-cavity ratio is therefore essentially a cubic amplification of the linear ratio index. When HTD falls below 12, the tumor diameter exceeds one twelfth of the height; translated to volume, the relative occupancy of the abdominal cavity enters a range that markedly compresses the operating space. Consider an infant 80 cm tall with an HTD of 10: the tumor diameter is then 8 cm and its volume about 268 cm^3, nearly filling the available upper abdominal workspace. In our data the TAVR cutoff was 0.029, and its discriminative ability (AUC 0.772) was almost identical to that of ACD. That two measurements differing in dimension and error source point in the same direction gives me confidence in the robustness of the result.

From an anatomical standpoint, the special structure of the pediatric abdominal cavity amplifies the clinical significance of relative burden. The robotic arms must keep a minimum spacing outside the body to avoid collision, but the small abdominal wall of an infant forces the trocars closer together, increasing arm interference and reducing dexterity. When the tumor is large, the effective intra-abdominal working radius of the instruments shrinks further, and external collision and internal compression combine. The infant renal artery is often less than 3 mm in caliber, and the renal pedicle is hard to expose when displaced by a large tumor. Once bleeding starts, the limited abdominal

volume leaves little room for coordinated suction, compression, and clamping, and the operative field deteriorates quickly. Major hemorrhage was the single most common complication in our series (11 cases, 8.6%), which I attribute to this mechanism. In addition, the infant peritoneum is thin and the abdominal cavity has limited compliance; when a large tumor occupies a substantial volume, the bowel and other organs have little room to be displaced, exposing the renal hilum requires greater traction, and the risk of injury to adjacent organs rises. In our series the two bowel injuries and the single renal pedicle vessel injury all occurred in children with low HTD or low ACD, which supports this inference.

From a hemodynamic and physiological-reserve standpoint, relative burden also influences surgical outcomes indirectly. In younger children or those with a high tumor-to-body ratio, intraoperative pneumoperitoneum lifts the diaphragm and affects venous return more, and the threshold for tolerating blood loss is lower. We defined major hemorrhage as estimated blood loss of at least 10% of the child's estimated blood volume or a need for intraoperative transfusion, a standard that is itself tied to body size and blood volume; the ratio index echoes this physiological threshold at the geometric level. I paid particular attention to one detail: age, height, weight, and abdominal circumference did not differ significantly between the two groups, yet the ratio indices did. This is a further, negative confirmation of the same mechanism. Risk does not depend on how large the child is, but on how much of the child the tumor occupies. If absolute body size were the dominant factor, children in the complication group should on the whole be smaller, but our data do not show that.

The criteria for case selection in minimally invasive pediatric renal tumor surgery have evolved from absolute diameter toward relative indices and, more recently, toward multidimensional risk quantification. Our study sits on the logical extension of this trajectory.

At the level of feasibility criteria, early SIOP practice used MTD < 10 cm as a reference for minimally invasive surgery, whereas the UMBRELLA SIOP-RTSG 2016 protocol refined the standard to tumor volume below 300 mL, central location, absence of vascular invasion, and a medial margin not crossing the lateral border of the ipsilateral vertebra.

Varlet and colleagues proposed small unilateral tumors with a medial margin not crossing the vertebral border as suitable, and noted that tumors exceeding 650 mL are difficult to control and that volumes above 500 mL are associated with high-risk disease. He and colleagues used TAVR < 15% as a feasibility threshold in their RALN cohort, and their contribution lies in incorporating age and weight. Our study distinguishes two different questions. TAVR < 15% addresses whether the operation can be completed by robot-assisted minimally invasive surgery, a question of feasibility; our HTD and ACD cutoffs address how high the risk of that minimally invasive operation is, a question of risk stratification. It is worth noting that our TAVR complication cutoff of 2.9% is far below the feasibility threshold of 15% proposed by He and colleagues, leaving a gray zone in which the operation is feasible but requires careful planning. In my view this gray zone is exactly where preoperative multidisciplinary discussion needs quantification, and where an absolute-diameter standard cannot help. The recent work of Pierucci and colleagues supports the clinical reasonableness of this gray zone: in their cohort, 32% of children had one or more formal contraindications to minimally invasive surgery, yet the off-criteria and on-criteria groups did not differ in complications, conversion rate, margin status, or recurrence, suggesting that in experienced centers the boundaries can be cautiously extended.

At the level of predictive indices, Fukuzawa and colleagues reported that a tumor-to-abdominal transverse diameter ratio above 0.5 is associated with intraoperative tumor rupture. Our ACD cutoff of 5.57 corresponds to an MTD-to-abdominal-circumference ratio above about 0.18, in the same direction but with a different measurement method (one uses transverse diameter, the other circumference). We used a composite intraoperative complication outcome covering rupture, major hemorrhage, organ injury, and conversion, which reflects overall surgical difficulty more comprehensively. The multiparametric imaging study of Oue and colleagues (hilar vessel relationship, tumor crossing the midline, tumor thrombus) corroborates our finding that no single absolute index is sufficient to predict surgical risk, and that the child's individual anatomical background must be considered. Gow and colleagues and Barber and colleagues reported risk factors for tumor spill based on large COG series, both pointing to tumor volume and stage rather than diameter alone. In adult kidney surgery, scoring systems such as

RENAL and PADUA quantify tumor complexity, but they were designed for fixed adult anatomy and cannot be scaled across ages. I have long held that a child is not simply a small adult: abdominal geometry, vessel caliber, and organ proportions all change nonlinearly with growth, so adult scoring systems cannot be transplanted directly. This is the methodological basis for our body-size ratio approach.

The age subgroup analysis showed that the HTD cutoff was 10.33 in children 24 months or younger, clearly lower than the 14.44 in older children, meaning that the risk threshold shifts earlier in infants. In clinically intuitive terms, a one-year-old child 80 cm tall enters the high-risk zone when the tumor diameter exceeds about 7.8 cm, whereas a six-year-old child 120 cm tall has a threshold relaxed to 8.3 cm. I noticed that using a uniform MTD cutoff of 8.3 cm would produce two systematic errors at once: underestimating risk in one-year-olds (whose true threshold is 7.8 cm) and overestimating risk in older children. This same-diameter, different-risk phenomenon cannot be recognized in studies based on absolute diameter, and I suspect it is one reason complication rates in the literature vary so widely (3% to 30%): cohorts differ in age composition, and the absolute-diameter standard lacks precisely the adjustment for age.

I understand the mechanism of threshold shift at three levels. First, the absolute abdominal volume of an infant is small, so at the same occupancy ratio the operating space is smaller and arm collision and instrument restriction are more prominent. Second, the renal pedicle vessels are thin, leaving less tolerance in vascular control; in our series the two pedicle-related complications (one renal pedicle vessel injury, and a substantial share of major hemorrhage arising from pedicle handling) clustered in young or low-ratio children. Third, young children have limited physiological reserve for bleeding, a small baseline blood volume, and therefore a higher relative blood loss for the same absolute loss, making them more likely to meet the definition of major hemorrhage. I should stress that, given the small size of the 24-month-or-younger subgroup (n = 15), the precision of this cutoff is limited, but its direction is consistent with anatomical expectation and with the overall framework of relative body-tumor burden. I still regard it as having clinical reference value, while stable extrapolation requires larger samples or external validation.

In my view, the clinical value of these results ultimately lies in an actionable decision pathway. On the basis of the HTD and ACD cutoffs, I propose a three-tier risk stratification embedded in the existing multidisciplinary team (MDT) framework.

For the low-risk group, defined by HTD ≥ 12 and ACD ≥ 5.6, RALN can proceed according to routine, without additional preparation. For the intermediate-risk group, marked by either index crossing its threshold, I suggest preoperative MDT discussion, blood preparation, full disclosure of the possibility of conversion to the family, and operation by a surgeon who has completed the learning curve. This group corresponds closely to the off-criteria but cautiously extendable interval described by Pierucci and colleagues. For the high-risk group, defined by HTD < 10.3 (the infant threshold) or by both indices crossing their thresholds, I suggest adequate neoadjuvant chemotherapy followed by re-measurement of the ratios to time the operation, with a routine contingency plan for open conversion.

The accessibility of measurement is a key prerequisite for translating this index into practice. ACD requires only a tape measure for the abdominal circumference and can be completed instantly at the outpatient visit at near-zero cost, which suits resource-limited settings. HTD depends on accurate height, which should be measured by dedicated staff in infants who cannot cooperate with standing measurement. Both are noninvasive, repeatable bedside indices. They complement volume-based indices such as TAVR, which rely on three-dimensional reconstruction or automated segmentation, forming a tiered division of labor: ACD and HTD for rapid outpatient triage, and TAVR for difficult cases that require precise quantification.

For children receiving neoadjuvant chemotherapy, the ratio indices also offer value for dynamic decision-making. Re-measuring HTD and ACD after each cycle can capture tumor shrinkage and allow de-escalation: if HTD rises from below 12 back above 12, surgical risk falls accordingly. This provides a simple tool for quantifying the timing of chemotherapy and surgery. This idea echoes the median 44.5% tumor volume reduction after chemotherapy observed by Pierucci and colleagues, extending risk stratification from a single preoperative judgment to dynamic management across the entire course of

treatment. I therefore regard this index as more than a predictive tool; it becomes a decision variable running through the whole chain of chemotherapy and surgery.

This study has limitations that should be weighed when interpreting the conclusions.

First, it is a single-center retrospective design. Between 2016 and 2024, robotic technology, the surgical learning curve, and perioperative management all evolved, and this time trend is a potential confounder. Although the operating team was relatively stable, we cannot fully exclude the effect of maturing technique on complication rates. The time span itself may dilute or amplify the true effect of the ratio indices. Future analyses should use time stratification or year-adjusted sensitivity analyses.

Second, the primary outcome is a composite. Major hemorrhage, rupture, organ injury, and conversion arise through different mechanisms, and the ratio indices may predict different subtypes with different strength. Because events were limited (25 cases), we could not model each subtype separately. With a larger sample, outcome-specific validation should be performed, particularly for tumor rupture, which bears directly on oncologic outcome through tumor spill.

Third, the cutoff values were derived within a single sample using the Youden index, which carries a risk of overfitting. Point estimates of AUC were not compared with the DeLong test, and the stability of the cutoffs requires bootstrap internal validation and external multicenter confirmation before they can be generalized. A single optimal cutoff also loses information on a continuous risk spectrum by hard dichotomization; in practice I suggest reporting both the raw ratio and the dichotomized result. Our multivariable model used the log-transformed ratio as a continuous variable, so the two approaches can serve as mutual references.

Fourth, abdominal circumference as a surrogate for abdominal volume carries systematic error. In obese children, abdominal circumference includes subcutaneous fat and may overestimate cavity volume and underestimate risk. Inter-observer agreement in circumference measurement was also not formally assessed. This error may cause the risk of some high-BMI children to be systematically underestimated through ACD.

Fifth, we did not include anatomical variables such as endophytic or exophytic growth, hilar vessel relationship, tumor crossing the midline, or tumor thrombus. These factors may complement the ratio indices, and combined modeling could further improve prediction, although over-parameterization should be guarded against; regularization or cross-validation is advisable when the sample is limited.

Several directions can be pursued. For validation, a prospective multicenter cohort should externally validate our cutoffs and explore individualized cutoff curves as a continuous function of age, replacing the current single age-band threshold. For modeling, HTD and ACD should be combined with tumor anatomical features (a modified RENAL or PADUA score, hilar relationship, direction of vessel displacement) to build a nomogram for multidimensional risk quantification, ready for direct use in MDT decisions. For technique, three-dimensional reconstruction and automated segmentation should be used to compute volume indices such as TAVR quickly before surgery, removing manual measurement error and moving volume ratios from a research tool into routine workflow. For dynamic assessment, the value of the ratio indices in evaluating response to neoadjuvant chemotherapy should be explored, building a quantitative model linking chemotherapy response to surgical timing. For outcome-specific and mechanistic work, tumor rupture, major hemorrhage, and conversion should be modeled separately in larger samples, combined with radiomics and vascular parameters, to test whether the geometric and hemodynamic hypotheses underlying the ratio indices hold.

HTD and ACD achieve individualized correction of tumor burden at a minimal measurement cost, and their ability to predict intraoperative complications exceeds that of the traditional absolute-diameter index. The differing age-subgroup cutoffs explain, at a data level, why tumors of the same diameter carry different risks in different children. In my view, the contribution of this study is not to reject the absolute-diameter standard but to add an individualized ruler to it, adding the dimension of tumor occupancy relative to the child's body size so that case selection and risk stratification move from one-size-fits-all to person-specific. I recommend HTD of 12.0 and ACD of 5.6 as general cutoffs for preoperative risk assessment in RALN, and an HTD cutoff tightened to 10.3 for infants 24 months or younger, as references for preoperative risk stratification, choice of surgical approach, and quantitative timing of neoadjuvant chemotherapy.

Conclusion

Body size-adjusted tumor ratios predict intraoperative complications during RALN more accurately than MTD alone. We suggest HTD of 12.0 and ACD of 5.6 as general cutoff values for preoperative risk assessment, with an HTD cutoff of 10.3 for infants 24 months of age or younger.

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Data availability The data that support the results of this study are available from the corresponding author, [Zhou Huixia], upon reason able request.

Declarations Conflict of interest All the authors have no conflict of interest or financial ties to disclose

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