Anatomic Features Involved in Technical Complexity of Partial Nephrectomy

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Nephrometry score systems, including RENAL nephrometry, preoperative aspects and dimensions used for an anatomical classification system, C-index, diameter-axial-polar nephrometry, contact surface area score, calculating resected and ischemized volume, renal tumor invasion index, surgical approach renal ranking score, zonal NePhRO score, and renal pelvic score, have been reviewed. Moreover, salient anatomic features like the perinephric fat and vascular variants also have been discussed. We then extract 7 anatomic characteristics, namely tumor size, spatial location, adjacency, exophytic/endophytic extension, vascular variants, pelvic anatomy, and perinephric fat as important features for partial nephrectomy. For novice surgeons, comprehensive and adequate anatomic consideration may help them in their early clinical practice. UROLOGY 85: 1–7, 2015. © 2015 Elsevier Inc.

Partial nephrectomy (PN) has emerged as the standard of care for small renal mass (SRM), which are most commonly malignant. Owing to the complex and technical nature of tumor exposure, tumor resection, and renal reconstruction involved in PN, a detailed understanding of renal tumor anatomy is necessary for comprehensive preoperative surgical planning. The current gold standard for assessment of kidney tumors is contrast-enhanced computed tomography (CT), which allows for assessment of vascular, kidney, and tumor anatomy and provides a reliable basis for preoperative planning. There have been several CT-based renal tumor score systems emerging that characterize renal tumor anatomy in a quantifiable manner since 2009, when the first nephrometry score system—RENAL nephrometry system—was published by Kutikov and Uzzo.1 We have performed a thorough search for PubMed, revealing 10 nephrometry score systems now being reported. A clear and comprehensive introduction of the nephrometry score systems is given in the following sections, which might need our further validation and perfection. And we are intending to develop a comprehensive and qualitative system to remind surgeons of the most prominent anatomic features during preoperative PN planning on the basis of these data as well as our own practical experience.

**RENAL NEPHROMETRY**

The RENAL nephrometry system, which was initially described in 2009 by Kutikov and Uzzo,1 is a standardized nephrometry scoring system based on 5 pertinent features to quantify the salient anatomy of renal masses on CT or magnetic resonance imaging. The acronym RENAL stands for tumor radius, exophytic and endophytic properties, nearness to the renal sinus or collecting system, anterior or posterior location, and location relative to the polar lines. Summation of points assigned for each feature yields the nephrometry score. Radius refers to the maximal diameter rather than the radius of the tumor in any plane (axial, sagittal, or coronal), and is scored on the TNM staging system. The exophytic and endophytic component is judged on percentage of tumor contained within the kidney periphery. Nearness refers to the proximity of the deepest portion of the tumor to the collecting system or renal sinus, which is scored on the basis of distances that mirror values for TNM size staging with the unit of millimeter. Polar location is measured on the basis of location of the tumor relative to the polar lines (ie, the plane of the kidney where the medial lip of parenchyma is interrupted by the renal sinus fat, vessels, or the collecting system). The only characteristic that does not factor into the numerical score is the anterior and posterior location, which is designated by A, P or X descriptors, whereas the addition of an H is given for hilar tumors. The nephrometry score is read as each individual component score in the order of the acronym along with a total score. Lesions with a nephrometry sum of 4, 5, or 6 are designated as low complexity, whereas masses with a sum of 7, 8, or 9 points are deemed to be of moderate complexity and those with 10, 11, or 12 points are the highest complexity lesions. An online measurement tool has been developed to facilitate calculation of RENAL score (www.nephrometry.com). On the basis of their

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classification system, the authors retrospectively quantified 50 consecutive renal masses and concluded that the RENAL score sum was lower (sum 4-6 and 7-9) in tumors that more often underwent PN using a minimally invasive approach, whereas lesions with a score of 10-12 were more likely to undergo laparoscopic radical nephrectomy or open PN. And their later data concluded that tumors with high RENAL scores were associated with a significantly higher major complication rate (21.9%) than those with intermediate (11.1%) or low (6.4%) scores \( (P = .009). \)

Study from Cleveland Clinic also supported that RENAL score and warm ischemia time were highly correlated (Spearman correlation coefficient \( = 0.54; P < .0001 \)), and there was a significant trend of higher warm ischemia time (WIT) with increased tumor complexity \( (P \text{ for trend} < .0001) \).

**PADUA CLASSIFICATION**

Another widely used nephrometry system is the preoperative aspects and dimensions used for an anatomical (PADUA) classification system, which is a standardized algorithm evaluating renal tumor anatomic complexity integrating tumor size and the other 6 important anatomic features including: (1) anterior or posterior location; (2) longitudinal location; (3) margin location; (4) relationship with the sinus; (5) relationship to the collecting system; and (6) tumor deepening into the parenchyma. The nephrometry system was described by Ficarra et al., who are from University of Padua in 2009. Each of the 7 features is given a score ranging from 1 to 3, with its final output as a single sum score. Renal masses with a PADUA score range of 6-7, 8-9, and 10-14 are deemed low, moderate, and high complexity lesions, respectively, with an “a” or a “p” suffix providing a descriptive element to the score sum. In its initial cohort, the PADUA score was found to be a predictor for the occurrence of overall complications: A moderate PADUA score (8 and 9) and a high score (10-14) meant separately a 14-fold and a 30-fold higher risk of complications as compared with low scores (6-7). An external validation study of the PADUA score system also concluded that patients with PADUA score \( \geq 8 \) had almost 20-fold higher risk of complications than those scored \(< 8 \) (hazard ratio \( = 19.82; 95\% \) confidence interval, 1.79-28.35; \( P = .015 \)). Data from China also arrived at the conclusion that higher PADUA score predicted longer operation time \( (P = .007) \), warm ischemia time \( (P = .001) \), and higher degree of blood loss \( (P = .003) \) in open PN patients.

**C-INDEX**

Centrality index (C-index) was proposed by Simmons et al as a means to quantify renal tumor centrality, on the basis of the notion that tumor size and central location are the 2 most critical determinants of technical difficulty. C-index was calculated by dividing the distance \( (c) \) between the tumor center and the kidney center by the tumor radius \( (r) \); however, the distance \( c \) was an indirect calculation base on a mathematical formula of the Pythagorean theorem. The nephrometry system was based totally on standard 2-dimensional cross-sectional CT images. A C-index of \( 0 \) equates to a tumor that is concentric with the center of the kidney; a C-index of \( < 1 \) has some portion of the tumor superimposed on the kidney center; a C-index of 1 equates to a tumor with its periphery touching the kidney center. And as the C-index increases, the tumor periphery becomes more distant from the kidney center. Thus, the higher the C-index, the lower is the central extension of the tumors, and nephron-sparing surgery should be more feasible with lesser chance of complications related to tumor location than in tumors with a low C-index. In the initial publication, ischemia and operating time tended to be longer and estimated blood loss was higher in tumors with a C-index \(< 2 \). As a measured value, C-index has the advantage of being quantitative, reproducible, and objective with interobserver variability only to be approximately 7%.

**DAP NEPHROMETRY**

Diameter-axial-polar (DAP) nephrometry was created as an offshoot scoring method integrating the optimized attributes of the RENAL and C-index scoring systems in 2012 by Simmons et al. It focuses on 3 features: tumor diameter, axial distance, and polar distance. DAP scoring is based on manual measurements using basic image viewing software rather than on sophisticated computerized analysis, thus being more user friendly and intuitive in clinical practice. It is also reported to be associated with decreased measurement error, improved performance characteristics, and improved interpretability. In the initial publication, DAP score was showed to have a clear association with volume loss and late function after PN. One study compared the DAP score system with the RENAL nephrometry system, and found that the area under the receiver operating characteristic curve of DAP \( (0.897) \) was better than that of RENAL nephrometry system \( (0.825) \) for deciding whether to implement laparoscopic PN (LPN).

**RENA L TUMOR INVASION INDEX**

Renal tumor invasion index (RTII) is a parameter describing the tumor parenchymal invasion depth in relation to the thickness of the renal parenchyma, calculated by dividing the invasion depth of the renal tumor by the parenchymal thickness. RTII is introduced by Nisen et al in 2014 and is very similar to C-index, which is also a quantitative variable, calculated by dividing the distance between the tumor center and the kidney center by the radius of the tumor. The major difference between the 2 indices may be the sensitivity area: RTII may be more accurate with superficial tumors and C-index with deeper ones. In their retrospective analysis of 280 patients, there were significantly more urologic complications in deep RTII group compared with moderate and superficial tumors \( (46.5\%, 25.2\%) \), and
and complications (Spearman correlation coefficient was with excellent interobserver concordance). Actually, this radiologically measurable parameter combines 2 pertinent anatomic parameters of tumor complexity, tumor size and degree of intraparenchymal extension, and is calculated by multiplying total surface area of the tumor with percentage of intraparenchymal component based on preoperative CT images using 3-dimensional imaging-rendering software. Total surface area of the tumor was calculated using the formula $4\pi r^2$ for surface area of a sphere, where $r$ equals tumor radius; whereas the volume of the tumor and the intraparenchymal components could be automatically calculated by the image processing software after the user manually renders the area of interest. On the basis of a retrospective series of 162 cases of minimally invasive procedures performed in their institution, the authors reported on the value of CSA as a predictor of PN outcomes. CSA as a dichotomized variable was a predictor of intraoperative blood loss $>500$ mL ($P = .005$), length of hospital stay $\geq4$ days ($P = .005$), and complications ($P = .008$). Furthermore, dichotomized CSA was considered a superior independent predictor of these outcomes than dichotomized tumor size, endophytic extension, or PADUA score. And the parameter was with excellent interobserver concordance (Spearman correlation coefficient = 0.91). But there are researchers questioning the scientificity of the study for testing this assumption.

**CONTACT SURFACE AREA**

Contact surface area (CSA) is a novel imaging parameter that quantifies the area of contact of a tumor with its surrounding uninvolved renal parenchyma. Actually, this radiologically measurable parameter combines 2 pertinent anatomic parameters of tumor complexity, tumor size and degree of intraparenchymal extension, and is calculated by multiplying total surface area of the tumor with percentage of intraparenchymal component based on preoperative CT images using 3-dimensional imaging-rendering software. Total surface area of the tumor was calculated using the formula $4\pi r^2$ for surface area of a sphere, where $r$ equals tumor radius; whereas the volume of the tumor and the intraparenchymal components could be automatically calculated by the image processing software after the user manually renders the area of interest. On the basis of a retrospective series of 162 cases of minimally invasive procedures performed in their institution, the authors reported on the value of CSA as a predictor of PN outcomes. CSA as a dichotomized variable was a predictor of intraoperative blood loss $>500$ mL ($P = .005$), length of hospital stay $\geq4$ days ($P = .005$), and complications ($P = .008$). Furthermore, dichotomized CSA was considered a superior independent predictor of these outcomes than dichotomized tumor size, endophytic extension, or PADUA score. And the parameter was with excellent interobserver concordance (Spearman correlation coefficient = 0.91). But there are researchers questioning the scientificity of the study for testing this assumption.

**RESECTED AND ISCHEMIZED VOLUME**

Resected and ischemized volume (RAIV) is a formula specialized for calculating resected renal parenchymal volume together with ischemized renal volume after renorrhaphy during PN surgery, intending to predict postoperative renal function. The substantially involved nephrons of both resected and ischemized volume could be mathematically calculated by integral calculus. The integral formula is comprised of 3 parameters: width regarding planned tumor margin and ischemized volume caused by renorrhaphy on the used individual procedure, deepest depth of the tumor involvement from the reference line, and radius of the tumor, and the formula was designed by a urologist and mathematically authenticated by a specialist on integral geometry. Comparative analysis between RAIV and current nephrometry systems such as RENAL score, PADUA score, and C-index was undertaken for its degree of association and predictability regarding severity of postoperative functional reduction; the results showed that RAIV displays a superior association with absolute change of estimated glomerular filtration rate.

**ZONAL NEPHRO SCORE**

The zonal NePhRO score system was devised on the basis of the notion that the surgical approach to any SRM is centered predominantly around 4 critical tumor parameters (as measured on preoperative imaging): size, location of the mass within the kidney, relationship to the collecting system, and spatial relationship of tumor to other organs or important vascular anatomy. In light of these parameters, the authors divided the kidney and the tumor into discrete anatomic zones: the first 2 components divide the kidney into anatomic zones and the latter 2 components divide the tumor into zones to assist with scoring. The NePhRO acronym stands for (Ne)phrometry to the collecting system, (Ph)ysical location of the tumor, tumor maximal (R)adius (actually diameter), and tumor (O)rganization. Once all 4 parameters have been scored, the individual numbers are tallied. Tumors are stratified into 3 complexity levels. Low-risk tumors are scored between 4 and 6, intermediate tumors are scored between 7 and 9, and high-risk tumors are scored between 10 and 12. This new system differentiates itself from the other scoring tools by dividing the kidney and the tumor into discrete anatomic zones and avoids cumbersome use of numbers with letters and observer-dependent polar lines. The authors reported on the value of NePhRO score as a predictor of nephron-sparing surgery outcomes in a retrospective series of 166 cases of open PN in their...
in institution. Perioperative complication occurrence was associated with the NePhRO score on both univariate \((P = .0043)\) and multivariate analyses \((P = .0008)\)\(^{17}\).

**SURGICAL APPROACH RENAL RANKING**

Surgical approach renal ranking (SARR) score system is another score system with much similarity to RENAL and PADUA nephrometry methodology with a few notable differences. The SARR score system takes into account the following 6 variables: tumor size, endophytic or exophytic, longitudinal location, extension of involvement of the renal parenchyma, relation with the renal sinus, and anterior or posterior location. Similar to the RENAL and PADUA systems, this score system forms a rating scale ranging from 4 to 17 points. The tumors were classified as being of low, medium, and high complexity whenever the score added up to 4-8, 9-12, and 13-17, respectively. According to their study involving 80 patients undergoing PN, the average surgery time, tumor size, and estimated bleeding increased according to the complexity of the tumor, as classified by the SARR scoring system, with a statistical significance \(P < .0001\), \(P < .0001\), and \(P = .036\), respectively.\(^{18}\)

All the above 10 renal tumor score systems were summarized in Table 1. The RENAL and the PADUA score systems have been validated externally to be effective, whereas others have not been accepted widely. There have been limited data to make a comparison of the available score systems, as illustrated in Table 2. These studies investigated the correlation of several score systems with the warm ischemia time, which is considered as the best surrogate of surgical complexity. All the 3 studies showed the C-index exhibiting the strongest correlation. These studies are in favor of the important role of tumor centrality in surgical complexity. The RENAL score and PADUA score have relatively lower correlation because the importance of tumor centrality has been diluted by not-so-important factors such as the polar location, which have been scored equally with the important ones in both the score systems. With the introduction of several other score systems, further investigation is imperative to validate their effectiveness and compare the different score systems, so as to pick up the best ones according to different purposes. In addition to these anatomic features centered entirely on tumor-specific factors, there are other patient-specific important features that have been omitted by these score systems for an easy scoring process or for their specific purposes. Among them, perinephric fat and renal vascular variants are the 2 most prominent ones that a surgeon has to take into consideration.

**PERINEPHRIC FAT**

The quantity and the quality of the perinephric fat put great influence on the technical difficulty during PN. Many surgeons may have been familiar with the experience of digging through thick and adherent perinephric adipose tissue to mobilize a kidney and expose

### Table 1. The 10 available renal tumor score systems

<table>
<thead>
<tr>
<th>Renal Tumor Score System</th>
<th>Publication Year</th>
<th>Institution</th>
<th>Main Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RENAL Nephrometry Score</td>
<td>2009</td>
<td>Temple University</td>
<td>Surgical complexity and outcomes</td>
</tr>
<tr>
<td>PADUA classification</td>
<td>2009</td>
<td>University of Padua</td>
<td>Surgical complexity and outcomes</td>
</tr>
<tr>
<td>C-index</td>
<td>2010</td>
<td>Cleveland Clinic</td>
<td>Surgical complexity and outcomes</td>
</tr>
<tr>
<td>DAP nephrometry</td>
<td>2012</td>
<td>Cleveland Clinic</td>
<td>Surgical complexity and outcomes</td>
</tr>
<tr>
<td>Renal tumor invasion index</td>
<td>2014</td>
<td>University of Helsinki</td>
<td>Urologic complications</td>
</tr>
<tr>
<td>Contact surface area</td>
<td>2014</td>
<td>University of Southern California</td>
<td>Surgical complexity and outcomes</td>
</tr>
<tr>
<td>Renal pelvic score</td>
<td>2014</td>
<td>Temple University</td>
<td>Postoperative urine leak</td>
</tr>
<tr>
<td>Resected and ischemized volume</td>
<td>2014</td>
<td>Yonsei University</td>
<td>Postoperative renal function</td>
</tr>
<tr>
<td>Zonal NePhRO score system</td>
<td>2014</td>
<td>Moffitt Cancer Center</td>
<td>Surgical complexity and outcomes</td>
</tr>
<tr>
<td>Surgical approach renal ranking</td>
<td>2014</td>
<td>Federal University of Sao Paulo</td>
<td>Surgical complexity and outcomes</td>
</tr>
</tbody>
</table>

DAP, diameter-axial-polar; PADUA, preoperative aspects and dimensions used for an anatomical classification system.

### Table 2. Correlation between score systems and warm ischemia time: results from different studies

<table>
<thead>
<tr>
<th>Authors</th>
<th>Year</th>
<th>Sample Size</th>
<th>Surgical Procedure</th>
<th>Tumor Size*</th>
<th>RENAL Score*</th>
<th>PADUA Score*</th>
<th>C-index*</th>
<th>DAP Score*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Okhunov et al(^{19})</td>
<td>2011</td>
<td>101</td>
<td>Laparoscopic PN</td>
<td>—</td>
<td>0.32</td>
<td>0.25</td>
<td>-0.44</td>
<td>—</td>
</tr>
<tr>
<td>Bylund et al(^{20})</td>
<td>2012</td>
<td>162</td>
<td>Open, laparoscopic, or robot-assisted PN</td>
<td>0.353</td>
<td>0.393</td>
<td>0.371</td>
<td>-0.482</td>
<td>—</td>
</tr>
<tr>
<td>Wang et al(^{21})</td>
<td>2014</td>
<td>69</td>
<td>Robotic PN</td>
<td>0.577</td>
<td>0.313</td>
<td>0.499</td>
<td>-0.609</td>
<td>0.593</td>
</tr>
</tbody>
</table>

DAP, diameter-axial-polar; PADUA, preoperative aspects and dimensions used for an anatomical classification system; PN, partial nephrectomy.

* Coefficient of univariate Spearman correlation analysis.
renal vessels in preparation for treatment of a SRM on an obese patient. Although body mass index (BMI) is widely used as a surrogate for the degree of obesity, studies have failed to show association between BMI with increased technical difficulty of PN.22-24 BMI does not distinguish between fat and muscle weight or between visceral and subcutaneous fat. It is the perinephric fat that more likely leads to poor surgical exposure during the crucial steps of renal hilar dissection, tumor excision, and renorrhaphy.25 The perirenal fat thickness, which was defined as the distance from the renal capsule to the lateroconal fascia on the line extending to the renal vein, was measured on a CT image at the level of the renal hilum. Anderson et al26 reported that a significant positive relationship existed between perirenal fat thickness and operative time in hand-assisted laparoscopic donor nephrectomy. Macleod et al27 compared perirenal fat measurements with BMI and abdominal fat as predictors of operative complexity during robot-assisted PN. They concluded that perinephric fat measurements but not BMI or abdominal fat were associated with both increased estimated blood loss and increased operative time.

Beyond the quantity of perinephric fat, the quality of the fat may also play a great influence on the technical difficulty of PN. Sticky perinephric fat, which was described as “dense,” “adherent,” “sticky” or similar terms in the operation record, can be a challenge for the surgeon in the process of mobilizing the kidney or exposing the renal vessel in PN. Median total operative time for patients with sticky fat was nearly 40 minutes longer than that for the control group patients.28 The quality and quantity of the fat are not independent of each other. Thickness of perinephric fat, as well as sex, age, tumor size, perinephric stranding, and exophytic nature, has been shown to be associated with this sticky fat phenomenon. And the slight chronic inflammation resulting from metabolic syndrome, which is defined as the presence of visceral obesity, has proved to activate a network of inflammatory signaling pathways, leading to sticky fat.29 To measure the “sticky fat,” Zheng et al30 proposed the perinephric fat surface density, which is based on CT density measurements by ImageJ (Version 1.47f; Research Services Branch, National Institute of Mental Health, Bethesda, MD). Their result showed that perinephric fat surface density demonstrated a significant capability to predict the difficulty of the perinephric fat dissection because of the presence of highly adherent “sticky” fat. Recently, Davidiuk et al31 introduced an imaged-based scoring system, called Mayo Adhesive Probability (MAP) to predict the possibility of the presence of intraoperative adherent perinephric fat. Their MAP score was based on posterior perinephric fat thickness and stranding with a range of 0-5 points. The proportion of patients with adherent perinephric fat for each level of the MAP score was as follows: 0 (n = 36; 6%), 1 (n = 19; 16%); 2 (n = 16; 31%), 3-4 (n = 11; 73%), 5 (n = 12; 100%).31 These works might help people to evaluate the impact of sticky fat on PN difficulty.

RENAL VASCULAR VARIANTS

Renal vascular variants involved arteries and veins and could be variations of course and number. Knowledge of renal vascular variants is important and crucial before LPN because it has major clinical implications in practice and may contribute to the safety of renal and retroperitoneal surgery. The most common variant is accessory renal arteries, which could be categorized according to their course as either polar (piercing the upper or lower pole of the kidney directly) or hilar (entering the kidney at the hilum). There are about one-third of the people having accessory renal arteries. The presence of accessory renal arteries might lead to an incomplete hilar clamping during LPN, causing an excessive intraoperative bleeding and high possibility of urologic complications or positive cancer margin secondary to compromised operative field. Early branching of the renal artery is another common variant with inconsistent definitions, as any branch diverges within 1 cm, 1.5 cm, or 2.0 cm from the lateral wall of the aorta in the left kidney or in the retrocaval segment in the right kidney. This variant is important in renal transplantation because most surgeons usually require at least a 1.5- to 2.0-cm length of renal artery before first branching for successful anastomosis.32 And in LPN, it depends on the position you reach: If you reach the trunk or all the branches, you could clamp the hilar perfectly, but if you reach one of the branches and are unaware of the existence of other parallel branches, you might arrive at the same outcome that we have discussed in the setting of accessory arteries. Multiple renal veins, late venous confluence, circumaortic left renal vein, and retroaortic left renal vein are 4 kinds of common venous variants; their clinical impact on LPN is low. But identification of these variants preoperatively might decrease the possibility of inadvertent venous injury.

As with most challenges in life, complex renal vascular anatomy during LPN also offers the urology surgeons opportunities. With the advent of zero ischemia LPN, urologists have tried to perform selective or segmental renal artery clamping technique. The accessory arteries perfuse anatomically equivalent regions of the kidney; an upper polar artery is a separate apical artery and an inferior polar artery is a separate lower segmental artery. Clamping a tumor-feeding accessory artery outside the renal is far easier than the meticulous microdissection of renal arterial branches adjacent to renal hilum or even into the renal sinus to clamp the tumor-specific tertiary artery.

As we described, there are already 10 score systems that characterize renal tumor anatomy in a quantifiable manner, including RENAL nephrometry, PADUA nephrometry, C-index, DAP nephrometry, contact surface area CSA score, calculating resected and RAIV, RTII, SARR score, zonal NePhRO score, and renal pelvic score. But to achieve an easy scoring process and for their unique purposes, these systems did not include all surgically relevant anatomic features, namely characteristics of the perinephric fat and the presence of vascular anatomic variants. To summary these relevant
anatomic features in a comprehensive and qualitative way, we extract 7 main features, as described in Table 3. The 7 important anatomic features involved in technical complexity of PN surgery that are summarized in the present review would help young surgeons to focus on the important anatomic features concerning with a renal mass and facilitate them to improve surgical experience and skills. For novice surgeons, comprehensive and adequate anatomic consideration may help them to operate in a more confident manner and bring them early success. When it comes to clinical decision making, the physician has to consider and integrate patient variables, tumor variables, and his or her own experience in a complex mind process to make a recommendation.

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References


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