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Three-dimensional topology-based T-index as an indicator of surgical difficulty of partial nephrectomy in patients with small renal mass

Dongkyu An[1], Dae Chul Jung[1], Jungwook Lee[1], Kyunghwa Han[2], Seungsoo Lee[3], Ki Don Chang[4], Koon Ho Rha[5]

[1]Department of Radiology, Severance Hospital, Yonsei University College of Medicine, Seoul, [2]Research Institute of Radiological Science and Center for Clinical Imaging Data Science, Severance Hospital, Yonsei University College of Medicine, Seoul, [3]Department of Radiology, Research Institute of Radiological Science and Center for Clinical Imaging Data Science, Yongin Severance Hospital, Yonsei University College of Medicine, Yongin, [4]Department of Urology, Yonsei University Wonju College of Medicine, Wonju, [5]Department of Urology, Severance Hospital, Yonsei University College of Medicine, Seoul, Korea

Purpose: To accurately describe the three-dimensional topology of renal tumors, our study suggests a new nephrometry scoring system, the T-index, that combines information about intraparenchymal extension and peripherality of the renal tumor.

Materials and Methods: This study included 113 patients who underwent partial nephrectomy for small clear cell renal cell carcinoma between 2007 and 2014. Manual segmentation of the renal parenchyma, sinus, and tumor was performed using preoperative computed tomography images. The T-index was calculated by adding the reciprocals of the distances from all points on the tumor-parenchyma interface to the renal sinus. Correlations with perioperative factors and the impact of the T-index on postoperative complications were evaluated and compared with existing nephrometry scoring systems (PADUA, RENAL, contact surface area [CSA], and C-index).

Results: The mean value of the T-index among the 113 patients was 116.1±100.5 (1/mm). The T-index showed the strongest correlation with perioperative factors compared with other nephrometry scoring systems. The T-index was able to predict the risk for postoperative complications, either overall (p=0.015) or major complications (p=0.030). A predictive model based on the T-index of the overall postoperative complications presented the best performance (area under the curve, 0.692; 95% CI, 0.599–0.776) compared with other nephrometry scoring systems.

Conclusions: The T-index can be considered as a single value comprising key structural indicators for surgical complexity. Our findings suggest that the T-index can provide a quantitative and objective scoring system associated with surgical difficulty and postoperative complications of partial nephrectomy.

Keywords: Carcinoma, renal cell; Nephrectomy; Postoperative complications

INTRODUCTION

The incidence of renal cell carcinoma (RCC) is increasing, with an estimated 431,288 new cases and 179,368 deaths worldwide [1,2]. This increase is mainly due to the increasing number of patients with early-stage RCC that is detected

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Corresponding Author: Dae Chul Jung https://orcid.org/0000-0001-5769-5083
Department of Radiology, Yonsei University College of Medicine, 50-1 Yonsei-ro, Seodaemun-gu, Seoul 03722, Korea
TEL: +82-2-2228-7400, FAX: +82-2-393-3035, E-mail: daechul@yuhs.ac

incidentally as the use of cross-sectional imaging, such as computed tomography (CT) and magnetic resonance imaging, becomes more common [3]. There are two options for the surgical treatment of RCC: radical nephrectomy and partial nephrectomy (PN). PN is now the standard of care for most tumors less than 4 cm in size (T1a), and it is an emerging option for select tumors sized 4 to 7 cm (T1b), with oncologic equivalency comparable with radical nephrectomy [4,5]. Additionally, with increasing evidence of the beneficial effects of preserved renal function, the indications for PN have been carefully expanded to include tumors with complex surgical anatomy [6,7].

Renal function after PN is affected by numerous variables, including preoperative functional status, warm ischemia time (WIT), and the percentage of functional volume resection [8]. The anatomic complexity of the renal tumor is an important factor for predicting surgical difficulty, postoperative functional outcome, and oncologic outcomes. Previous nephrometry systems such as PADUA, RENAL, C-index, contact surface area (CSA), and SPARE are all composed of anatomical factors and have been validated to be associated with perioperative outcomes [4,9-12]. However, because the measurements and calculations used in those scoring systems were performed by using two-dimensional (2D) images and were overfitted by using a mathematical model, those scoring systems cannot fully represent the real anatomical (surgical) complexity of the tumor.

This study aimed to develop a three-dimensional (3D) tumor index integrating three anatomic parameters of surgical complexity: size, degree of intraparenchymal extension, and tumor proximity to the renal sinus and hilum. The suggested 3D tumor index was evaluated as a potential indicator for surgical difficulty and long-term complications of PN. It is hypothesized that the new 3D volume-based imaging parameter could improve preoperative radiologic evaluation and standardize surgical planning for PN in patients with RCC.

MATERIALS AND METHODS

1. Study population

This study was approved by the Institutional Review Board of Yonsei University College of Medicine (approval number: 4-2020-0533), and the requirement for informed consent was waived. Between September 2007 and December 2014, a total of 254 patients who underwent PN performed by a single surgeon for renal tumors were identified through a review of electronic medical records. Among those patients, 141 were excluded for the following reasons: no available preoperative CT study with contrast enhancement or corticomedullary phase (n=35), low image quality of preoperative CT study (n=5), multiple renal lesions (n=1), cystic lesion (n=9), non–clear cell type of RCC (n=58), lesion size greater than 5.0 cm (n=22), and recurrent tumor (n=1). Finally, 113 patients were evaluated (Fig. 1). Consecutive patients had preoperative multiphase kidney CT images available for analysis, and the final pathologic report of their renal lesion and perioperative and postoperative follow-up data were obtained from the database. All included patients were followed up as much as possible for up to 7 years; the mean follow-up period was 45.6 months (95% confidence interval [CI], 41.08–50.18 mo).

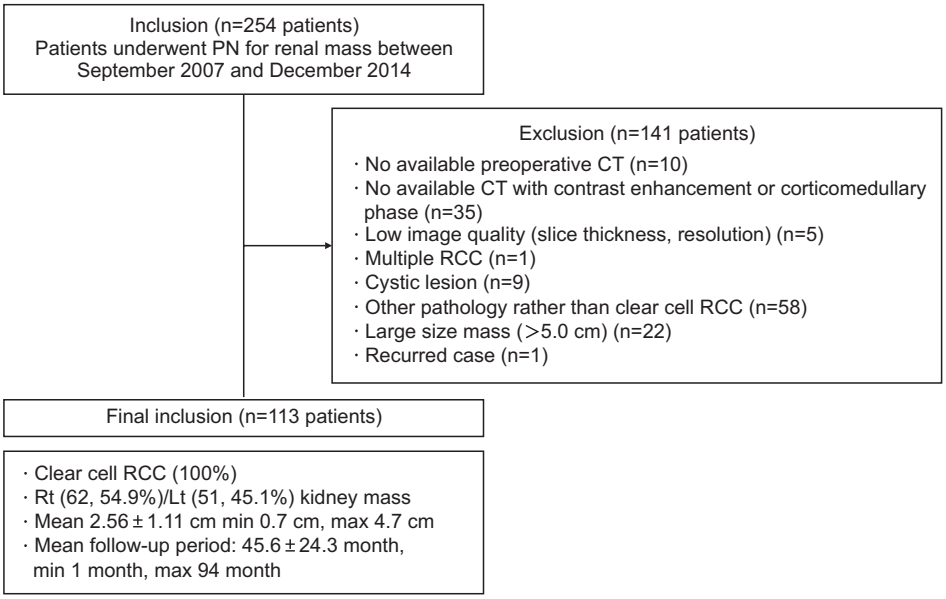

Fig. 1. Flow diagram of patient enrollment. CT, computed tomography; PN, partial nephrectomy; RCC, renal cell carcinoma.

2. Kidney CT examination and segmentation of renal tumor and sinus

Multiphase kidney CT was performed with one of three helical CT scanners (Discovery CT 750 HD, GE Healthcare; iCT256, Philips Healthcare; or Somatom Definition Flash, Siemens Healthcare). CT images were obtained during the unenhanced phase, corticomedullary phase, and nephrographic phase, with breath-holding during each phase. The CT protocol was as follows: axial plane; 100 kVp; variable tube current; and section thickness of 3 mm. After intravenous injection of 100 to 150 mL of nonionic contrast agent (IOBRIX® inj.240, Taejoon Pharm Co.) dosed to weight with a power injector at a rate of 3–4 mL/s, a bolus tracking method was applied to determine the start of corticomedullary phase imaging (range, 20–45 s). Nephrographic phase imaging was conducted 120 seconds after contrast injection. All CT images were archived using PACS (PathSpeed Workstation, GE Healthcare) for image analysis.

Volume data from the preoperative CT images were acquired using 3D rendering software (3D-slicer, NIH, version 4.13.0). All images underwent preprocessing as follows: window level of the image was normalized to [0, 255], and the pixel size and slice thickness were normalized to 0.98 mm^2 and 3 mm, respectively [13]. The parenchyma of the bilateral kidneys and tumor were segmented manually, and 3D reconstruction was performed (Supplementary Fig. 1). The renal sinus was described by a convex hull of embedded area into the kidney, based on 3D information on the kidney parenchyma.

3. Extract T-index

Through the process of segmentation and labeling of the renal mass and sinus by use of the 3D rendering software, we can obtain 3D information on the renal parenchyma, mass, cyst, and sinus. The proposed novel nephrometry index, the T-index, reflects the extent of contact surface between the renal tumor and parenchyma and the distance between the renal tumor and hilum. Using the 3D volume information, we measured the distance between each point of the tumor-parenchyma interface and the center point of the renal hilum. Then, we summed the reciprocal of each measured distance (in millimeters) through the whole tumor-parenchyma interface using NumPy (Python, version 3.9.8). If a mass invaded the renal sinus, the value obtained through the same process for the tumor-sinus interface was added up. These processes were repeated through every labeled kidney tumor, and each result was considered as the T-index (Fig. 2, Supplementary Fig. 2).

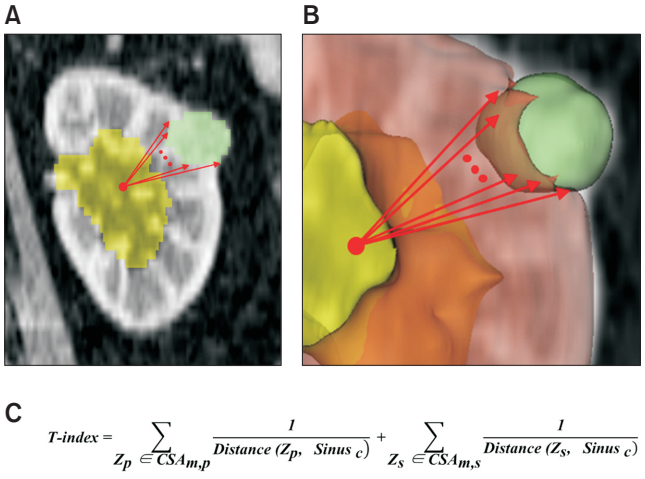

Fig. 2. Conceptual image showing the extraction of distance between the tumor-parenchyma interface and the center of the renal sinus as (A) 2D and (B) 3D images. The T-index can be expressed as a formula (C), where $CSA_{m,p}$ is the mass and the CSA of the kidney parenchyma, and Z_p is the single point drawn from $CSA_{m,p}$. $CSA_{m,s}$ and Z_s correspond to the mass-renal sinus interface. 2D, two-dimensional; 3D, three-dimensional; CSA, contact surface area.

4. Statistical analysis

WIT, estimated blood loss (EBL), operation time (OT), total days of hospital stay (THS), and absolute change in creatinine between preoperative and postoperative values (Cr-diff) were considered as perioperative clinical variables correlated with surgical difficulty. Kidney function was assessed by estimated glomerular filtration rate (eGFR) and categorized by chronic kidney disease (CKD) stage based on the NICE guidelines (stage 1: eGFR≥90 mL/min/1.73 m^2; stage 2: 60≤eGFR≤89; stage 3: 30≤eGFR≤59; stage 4: 15≤eGFR≤29; stage 5: eGFR<15) [14]. CKD stage 3 or higher was regarded as clinically significant CKD, and each patient was classified as having postoperative CKD development during the follow-up period (Group B) or not (Group A). The 3-month postoperative complications were classified according to the modified Clavien–Dindo system. Postoperative complications were distinguished as minor (grade I–II) and major (grade III–IV) [15].

Spearman correlation analysis was performed to measure the strength of the relationship of the T-index with perioperative variables and percentage decrease in eGFR. Additionally, we calculated correlation coefficients between the above variables and classic nephrometry indices, including RENAL, PADUA score, CSA, and C-index. All correlation coefficients were z-transformed for comparison between each index [9]. Postoperative complication predictability was assessed by logistic regression analysis based on postoperative CKD development. Predictive models based on nephrometry systems were evaluated and compared by area under curve

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(AUC).

All analyses were performed using Python v3.6.9 and scipy v1.4.1, and a two-sided p-value <0.05 was considered as statistically significant.

RESULTS

Demographic characteristics, preoperative and perioperative clinical information, and nephrometry scores (PADUA score, RENAL score, C-index, CSA, and T-index) of the 113 patients are listed in Table 1.

1. Predicting surgical difficulty according to perioperative variables

As shown in Table 2, the T-index was significantly associated with five perioperative factors: OT (r=0.261; p=0.006), Cr-diff (r=0.427; p<0.001), THS (r=0.194; p=0.042), WIT (r=0.621; p<0.001), and EBL (r=0.243; p=0.011). Other nephrometry systems (PADUA, RENAL, C-index, CSA) were not perfectly correlated with perioperative factors; PADUA was significantly correlated with WIT, RENAL was correlated with Cr-diff and WIT, and C-index was correlated with OT and WIT.

2. Predicting risk for postoperative complications

A total of 17 patients experienced postoperative complications after PN. Those complications were classified as grade I to IV according to the modified Clavien–Dindo system; 7 cases were grade I, 4 were grade II, and 6 were grade III (Table 1). None of complications was considered a grade IV complication. Examples of the major complications of grade III or higher included bleeding requiring an interventional procedure (four cases), ureteral injury requiring an indwelling ureteral stent (one case), and intraoperative bowel perforation (one case).

Interestingly, the T-index was able to predict the risk for postoperative complications, either overall (p=0.015) or major complications (p=0.030). Multivariable analysis also showed the T-index (p=0.023) as the only independent predictor for overall postoperative complications (Table 3A, B).

Fig. 3 shows the accuracy of the predictive models generated from different nephrometry systems to predict overall complications. Each predictive model was based on multivariable logistic analysis including clinically significant variables: preoperative eGFR, age, sex, body mass index, American Society of Anesthesiologists (ASA) score, and underlying history. The predictive model based on the T-index presented the best performance (AUC, 0.692; 95% CI, 0.599–0.776) compared with the other nephrometry systems (Table 4). When our study confined the major postoperative complications more strictly to bleeding requiring interventional procedures only, univariate logistic regression analysis showed that the T-index was a significant predictor with an odds ratio of 1.013 (95% CI, 1.004–1.022) and a p-value of 0.0042. However, in the multivariate logistic regression analysis, the

Table 1. Demographic characteristics, perioperative characteristics, and nephrometry scores of the 113 patients included in the analysis

Variable	Value
Preoperative clinical information	
eGFR (mL/min/1.73 m^2)	85.4±17.5
Age (y)	53.3±12.1
Sex (male)	80 (70.8)
Height (cm)	167±8.36
Weight (kg)	69.5±11.6
BMI (kg/m^2)	24.9±3.71
ASA score	1 (1–3)
CCI	3 (2–7)
HTN, yes	37 (32.7)
DM, yes	14 (12.4)
CKD stage	
1	81 (71.7)
2	25 (22.1)
3	4 (3.5)
4	3 (2.7)
Tumor location, right	62 (54.9)
Perioperative information	
Tumor size (cm)	2.56±1.11
OT (min)	171.5±91.3
Cr-diff (mg/dL)	-0.69±8.76
THS (d)	5.51±1.86
WIT (min)	21.0±13.0
EBL (mL)	442±959
Postoperative complications	17 (15.0)
Grade 1	7 (6.2)
Grade 2	4 (3.5)
Grade 3	6 (5.3)
Nephrometry scores	
PADUA score	8.89±1.76
RENAL score	7.39±1.88
C-index (cm)	2.97±1.04
CSA (mm^2)	38.96±10.36
T-index (1/mm)	116.1±100.5
Patient classification by postoperative CKD development	
Non-CKD-developing (Group A)	89 (78.8)
CKD developing (Group B) (preop CKD stage→postop CKD stage)	14 (12.4)
1→3	7
1→4	1
2→3	4
2→4	2

Table 1. Continued

Variable	Value
Predisposed CKD	7 (6.2)
No optimal follow-up (less than 6 mo)	3 (2.7)

Values are presented as mean±standard deviation, number (%), or median (range).
eGFR, estimated glomerular filtration rate; BMI, body mass index; ASA, American Society of Anesthesiology; CCI, Charlson comorbidity index; HTN, hypertension; DM, diabetes mellitus; CKD, chronic kidney disease; OT, operation time; Cr-diff, absolute change in creatinine between preoperative and postoperative creatinine values; THS, total days of hospital stay; WIT, warm ischemia time; EBL, estimated blood loss; CSA, contact surface area.

odds ratio was 1.011 (95% CI, 0.999–1.023) and the p-value was 0.072, which was not significant.

3. Postoperative CKD development and predictive model based on the T-index

Among 113 study patients, 14 patients showed postoperative CKD development during the follow-up period (Group B), while 89 patients did not (Group A). Detailed information on CKD stage alterations in Group B is described in Table 1. Ten patients were excluded from this evaluation owing to predisposed CKD and a short follow-up period. Between Groups A and B, age, Charlson comorbidity index (CCI), hypertension, diabetes mellitus, tumor size, Cr-diff, and the T-index showed significant differences, as evaluated by the Mann–Whitney U test (Supplementary Table 1).

In the multivariable logistic regression analysis including significant predictors, preoperative eGFR, age, and the T-index were significant independent predictors of postoperative CKD development (Table 5A, B). Also, the predictive model based on the T-index showed noninferior predictability (AUC, 0.873; 95% CI, 0.793-0.931) compared with predictive models derived from other existing nephrometry systems (Supplementary Fig. 3, Supplementary Table 2).

DISCUSSION

We developed a novel nephrometry parameter, the T-index, that is based on 3D topology reconstructed from CT images. The index is a single surrogate marker of three key indicators of surgical difficulty: 1) tumor size, 2) degree of intraparenchymal extension, and 3) anatomical distance between the tumor and the renal sinus. This represents an extraordinary attempt to organize a nephrometry index from realistic 3D topology without simplification or categorization. Additionally, the present study shows that a larger T-index suggests greater difficulty of PN and a risk for long-term

Table 2. Correlation and z-transformed correlation between nephrometry and perioperative variables

Perioperative variable	PADUA			RENAL			C-index			CSA			T-index		
	Correlation coefficient	z-transformed	p-value	Correlation coefficient	z-transformed	p-value	Correlation coefficient	z-transformed	p-value	Correlation coefficient	z-transformed	p-value	Correlation coefficient	z-transformed	p-value
OT	0.0869	0.0871	0.360	0.0765	0.0766	0.421	-0.257	-0.258	0.007	0.0606	0.6080	0.574	0.255	0.261	0.006
Cr-diff	0.161	0.163	0.088	0.253	0.259	0.007	-0.182	-0.184	0.053	-0.0609	-0.0611	0.522	0.403	0.427	<0.001
THS	0.0865	0.0867	0.362	0.103	0.103	0.280	-0.175	-0.176	0.064	-0.160	-0.163	0.091	0.192	0.194	0.042
WIT	0.29	0.299	0.002	0.351	0.366	<0.001	-0.244	-0.249	0.009	-0.169	-0.162	0.074	0.552	0.621	<0.001
EBL	0.162	0.164	0.086	0.0995	0.0998	0.294	-0.0327	-0.0327	0.731	-0.0842	-0.0851	0.377	0.238	0.243	0.011

CSA, contact surface area; OT, operation time; Cr-diff, absolute change in creatinine between preoperative and postoperative creatinine values; THS, total days of hospital stay; WIT, warm ischemia time; EBL, estimated blood loss.

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Table 3A. Univariable analysis of factors with an impact on major postoperative complications and total postoperative complications

Variable	Major postoperative complications			Overall postoperative complications		
	OR	95% CI	p-value	OR	95% CI	p-value
Patient clinical information						
Preop_eGFR	0.986	0.943–1.031	0.524	1.004	0.974–1.034	0.818
Age	1.018	0.951–1.090	0.601	0.997	0.956–1.041	0.903
Sex	0.816	0.142–4.685	0.819	0.531	0.183–1.540	0.244
BMI	0.986	0.783–1.241	0.904	0.976	0.844–1.130	0.748
ASA 1 (vs. ≥2)	1.610	0.310–8.358	0.571	0.833	0.284–2.441	0.738
CCI	0.946	0.553–1.617	0.838	1.009	0.729–1.396	0.958
HTN	0.000[a]		0.998	0.587	0.177–1.945	0.384
DM	1.446	0.156–13.369	0.745	2.646	0.723–9.690	0.142
Tumor size	2.198	0.996–4.851	0.051	1.582	0.987–2.537	0.057
Nephrometry scores						
PADUA	1.458	0.903–2.356	0.123	1.193	0.892–1.597	0.237
RENAL	1.510	0.922–2.474	0.102	1.206	0.910–1.598	0.192
C-index	0.872	0.386–1.970	0.742	0.808	0.481–1.356	0.420
CSA	0.930	0.855–1.013	0.454	0.959	0.911–1.009	0.561
T-index	1.009	1.003–1.016	0.007	1.006	1.001–1.011	0.015

Preop_eGFR, preoperative estimated glomerular filtration rate; BMI, body mass index; ASA, American Society of Anesthesiologists; CCI, Charlson comorbidity index; HTN, hypertension; DM, diabetes mellitus; CSA, contact surface area.
[a]:OR of the HTN in major complication could not be calculated because no case with major complications had underlying HTN.

Table 3B. Multivariable analysis of factors with an impact on major postoperative complications and total postoperative complications

Variable	Major postoperative complications			Overall postoperative complications		
	OR	95% CI	p-value	OR	95% CI	p-value
Preop_eGFR	0.989	0.934–1.0473	0.703	0.995	0.962–1.030	0.776
Age	1.058	0.940–1.190	0.352	0.989	0.932–1.050	0.720
Sex	0.779	0.089–6.846	0.822	0.493	0.151–1.604	0.240
BMI	1.064	0.764–1.482	0.714	1.021	0.859–1.214	0.816
ASA 1 (vs. ≥2)	1.035	0.125–8.538	0.975	0.784	0.229–2.684	0.699
HTN	0.000[a]		0.998	0.344	0.061–1.932	0.226
DM	8.759	0.311–246.657	0.203	5.270	0.805–34.495	0.083
T-index	1.008	1.001–1.015	0.030	1.006	1.001–1.011	0.023

Preop_eGFR, preoperative estimated glomerular filtration rate; BMI, body mass index; ASA, American Society of Anesthesiologists; HTN, hypertension; DM, diabetes mellitus.
[a]:OR of the HTN in major complication could not be calculated because no case with major complications had underlying HTN.

complications.

Although the C-index and CSA have been used to evaluate tumor complexity based on topologic data, they have limitations because they are extracted from 2D CT images [4,16]. Furthermore, the CSA and C-index consider the tumor and kidney as spheres or ellipsoids to simplify the topological analysis and do not represent the actual 3D topology. To overcome these limitations of the previous nephrometry system, we suggested the T-index as a sum of the reciprocal of the distance between the kidney-tumor interface and the renal hilum based on 3D topology. Our use of advanced 3D rendering software allowed us to fully reflect the actual shape and location of the kidney and tumor. This means that the T-index consists of realistic topologic data of the tumor and renal parenchyma and can be considered as a single index comprising the three key indicators of surgical difficulty.

We proved that the T-index was significantly correlated with perioperative variables, reflecting the surgical difficulty of PN. Furthermore, the T-index could predict risk for postoperative complications better than any other existing nephrometry systems. According to these results, we suggest that the T-index, which reflects the tumor and kidney anatomy more elaborately, may provide more accurate information on PN surgical difficulty to surgeons.

Interestingly, the present study shows the possibility of

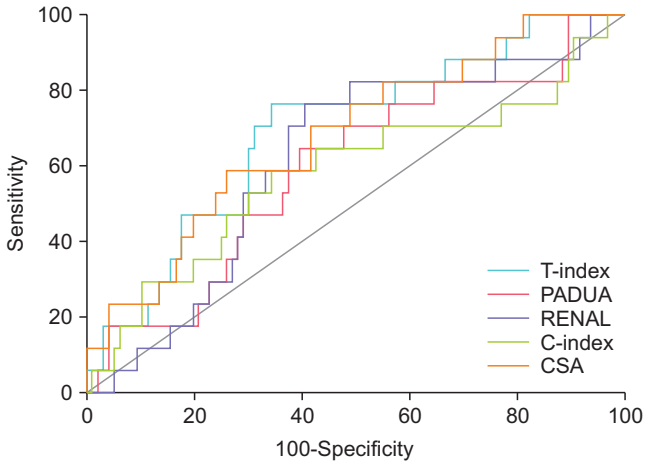

Fig. 3. ROC curve analysis showing the accuracy (AUC, 95% CI) of predictive models based on multivariable logistic regression analysis with different nephrometry scores to predict overall postoperative complications. Exact AUC (95% CI) values and the differences between the predictive models are presented in Table 4. AUC, area under curve; ROC, receiver operating characteristic; CSA, contact surface area.

Table 4. AUC analysis (95% CI) of predictive models based on multivariable logistic regression analysis with different nephrometry scores to predict overall postoperative complications

Predictive model	AUC	95% CI
T-index	0.692	0.599–0.776
PADUA	0.596	0.499–0.687
RENAL	0.620	0.524–0.710
C-index	0.583	0.487–0.675
CSA	0.682	0.588–0.766
Between predictive models	**AUC difference**	**p-value**
T-index and PADUA	0.097	0.012
T-index and RENAL	0.072	0.115
T-index and C-index	0.109	0.190
T-index and CSA	0.010	0.902

AUC, area under curve; CSA, contact surface area.

Table 5A. Univariable analysis of factors with an impact on postoperative CKD development

Variable	OR	95% CI	p-value
Patient clinical information			
Preop_eGFR	0.930	0.879–0.983	0.0108
Age	1.13	1.06–1.21	<0.001
Sex	0.743	0.227–2.430	0.623
BMI	1.07	0.919–1.25	0.377
ASA 1 (vs. ≥2)	0.986	0.305–3.21	0.986
CCI	2.41	1.55–3.74	<0.001
HTN	3.83	1.20–12.2	0.0234
DM	6.51	1.71–24.8	0.0061
Tumor size	1.65	0.993–2.73	0.0533
Nephrometry scores			
PADUA	1.23	0.939–1.79	0.115
RENAL	1.36	0.986–1.87	0.0613
C-index	0.838	0.471–1.49	0.547
CSA	0.930	0.855–1.013	0.454
T-index	1.005	0.9998–1.011	0.0604

CKD, chronic kidney disease; preop_eGFR, preoperative estimated glomerular filtration rate; BMI, body mass index; ASA, American Society of Anesthesiologists; CCI, Charlson comorbidity index; HTN, hypertension; DM, diabetes mellitus; CSA, contact surface area.

Table 5B. Multivariable analysis of factors with an impact on postoperative CKD development

Variable	OR	95% CI	p-value
Preop_eGFR	0.932	0.867–1.002	0.0564
Age	1.115	1.026–1.211	0.0101
HTN	1.467	0.295–7.292	0.6395
DM	2.355	0.354–15.68	0.3758
T-index	1.008	1.0003–1.0147	0.0404

CKD, chronic kidney disease; preop_eGFR, preoperative estimated glomerular filtration rate; HTN, hypertension; DM, diabetes mellitus.

using the T-index to predict postoperative CKD development. The T-index could predict the risk for postoperative CKD development through 7 years of follow-up, and the predictive model showed noninferior performance compared with other nephrometry systems, including CSA, which is known as the best predictor of preservation of renal function after PN. This finding indicates that accurate analysis of 3D topology may be valuable for predicting long-term complications, not only perioperative surgical difficulty.

Although the present study suggests the potential of the T-index as a novel nephrometry index, it is important to acknowledge the limitations of the study that may have influenced the results. First, there is a viewpoint that surgical difficulty or outcome is affected more by an individual surgeon's capability than by other clinical information. This "surgeon factor" has limited standardization of the assessment of PN surgical difficulty. It could be considered that the surgeon factor did not affect our results because all PN procedures were performed by a single surgeon. Nevertheless, an additional larger study including different surgeons' records is needed to control for the surgeon factor. Second, the acquisition protocol and image quality of the CT scans varied because of the long period of data collection. In addition, because our study was a single-center retrospective study, the number of patients enrolled was inevitably small. Besides, we were forced to limit the inclusion criterion to small clear cell RCCs so that we could form a homogeneous study population and so that we could prevent unexpected variables resulting from the segmentation process because

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of the various imaging features of the different pathologic subtypes of RCC. Therefore, further standardized research with large numbers and multiple centers will be needed to apply the T-index to clinical practice as a predictor of surgical outcome. Third, although we were aware that surgical details such as enucleation, bed suturing, tenorrhaphy, and the type of surgical suture could also affect surgical outcomes, it was practically difficult to identify and analyze all the details of every surgery. Therefore, we regarded analyzing PN performed by a single surgeon as an adequate means of accounting for these variables. Finally, application of the T-index in clinical practice could be limited by the time-consuming process of manually segmenting the renal mass and sinus and performing the calculations. However, recent advancements in technology, such as fast 3D graphic processing and automatic organ segmentation algorithms, have the potential to overcome these limitations. Developing an automated T-index extraction algorithm in future studies has the potential to significantly reduce the time required for calculation and increase the practical utility of the index. Additionally, further large-scale studies using computer systems for automatic T-index calculation may reveal more insights into the implications of 3D nephrometry.

CONCLUSIONS

Our study proposes a new nephrometry system called the T-index that is based on the 3D topology of the renal mass and the kidney. We insist that the T-index represents renal tumor complexity remarkably well and that the index is an accurate and comprehensive anatomical parameter. Although the T-index requires manual tumor labeling and sinus segmentation, the index has the distinct advantages mentioned above. We propose the T-index as an objective and quantitated index representing 3D topology. The index may have use as an indicator for surgical difficulty and a predictor of long-term complications to assist clinicians in preoperative decision-making.

CONFLICTS OF INTEREST

The authors have nothing to disclose.

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AUTHORS' CONTRIBUTIONS

Research conception and design: Dongkyu An, Dae Chul Jung, Jungwook Lee, Kyunghwa Han, Seungsoo Lee, Ki Don Chang, and Koon Ho Rha. Data acquisition: Dongkyu An, Dae Chul Jung, Jungwook Lee, Seungsoo Lee, and Ki Don Chang. Statistical analysis: Dongkyu An, Dae Chul Jung Jungwook Lee, and Kyunghwa Han. Data analysis and interpretation: Dongkyu An, Dae Chul Jung, and Jungwook Lee. Drafting of the manuscript: Dongkyu An, Dae Chul Jung, and Jungwook Lee. Critical revision of the manuscript: Dongkyu An, Dae Chul Jung, Jungwook Lee, Kyunghwa Han, Seungsoo Lee, Ki Don Chang, and Koon Ho Rha. Obtaining funding: Dae Chul Jung. Administrative, technical, or material support: Ki Don Chang and Koon Ho Rha. Supervision: Dae Chul Jung. Approval of the final manuscript: Dae Chul Jung.

SUPPLEMENTARY MATERIALS

Supplementary materials can be found via https://doi.org/10.4111/icu.20230041.

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