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Renal Carcinoma with Inferior Vena Cava Tumor Thrombus: Predictive Model of Tumor Invasion of Inferior Vena Cava Wall Using Multimodal Imaging

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Abstract

Purpose: *Tumor invasion of inferior vena cava (IVC) vascular wall is more channeled and required the IVC resection in the operation, and IVC infiltrated by IVCTT is considered to be a risk factor for recurrence and poor prognosis in renal cell carcinoma. We use preoperative prediction model based on multimodality image to evaluate the probability of invasion of IVC vascular wall because of tumor infiltrated.*

Materials and Methods: *We retrospectively analyzed the clinical data of 112 patients with RCC with level I-IV tumor thrombus who underwent radical nephrectomy and IVC thrombectomy between January 2014 and Apirl 2019. The patients were in in two groups, 86 patients were used to establish the imaging model , and data validation was performed in 26 patients. We measured imaging parameters in magnetic resonance imaging/computed tomography (MRI/CT) and ultrasound, evaluated the uni- and multivariable associations of clinical and radiographic features with IVC resection by logistic regression, and established an image prediction model to assess the probability of IVC vascular wall invasion.*

Results: *In all the patients, 46.5% (40/86) was IVC vascular wall invasion. The maximum coronal IVC diameter in MRI/CT , the absence of color flow signal in ultrasound image and with bland thrombus were significant risk factors in the univariate and multivariate analyses. We identified the residual IVC blood flow (OR 0.170; P = 0.007) , maximum coronal IVC diameter in mm (OR 1.203; P= 0.003)and with bland thrombus (OR 3.216; P= 0.080)as independent risk factors of IVC vascular wall. We predicted vascular wall invasion if the probability was > 50%, as calculated by:*

$$Ln\{\frac{pre}{1-pre}\} = 0.185 \times \max imum\ cornal\ IVC\ diameter + 1.168 \times bland\ thrumbus$$
$$-1.770 \times residual\ IVC\ blood\ \ flood\ -5.857$$

Prediction for IVC vascular wall invasion, 89.5% (77/86) was consistent with the actual treatment, and in the validation patients, 22/26 was consistent with the actual treatment.

Conclusions: *Our model of multimodal imaging associated with IVC vascular wall invasion may be used for preoperative evaluation and prediction of need for partial resection or segmental IVC resection.*

Keywords: *Multimodal Imaging, Inferior Vena Cava tumor Thrombus, Renal Cell Carcinoma, Preoperative Imaging, Inferior Vena Cava Invasion*

Abbreviations: *IVC Inferior Vena Cava, RCC Renal Cell Carcinoma, MRI Magnetic Resonance Imaging, CT Computed Tomography, TT Tumor Thrombus, AP Anterior–Posterior, RVO Renal Vein Ostium, ROC Receiver Operating Characteristic*

1. Introduction

Renal cell carcinoma (RCC) has a propensity for vascular growth [1], extending into renal venous or inferior vena cava (IVC) in approximately 4-10% of patients [2, 6] Radical nephrectomy with thrombectomy may be the curative option [7, 10] However, thrombectomy is risky and

technically challenging [6, 10, 12]. Tumor invasion of inferior vena cava (IVC) vascular wall is considered to be a risk factor for recurrence and poor prognosis in RCC. Besides, Tumor invasion of inferior vena cava (IVC) vascular wall is more channeled and required the IVC resection in the operation. The concept of IVC resection was defined in previous research [13]. According to the experience of resection IVCTT in our hospital, the influence of intraoperative invasion of IVC on IVC resection is shown in Fig.1.It referred partial or segmental IVC resection, which required vascular reconstruction using patch graft, or IVC resection and interruption. The management of IVC, whether it involves partial or segmental resection, is critical for surgery. When the tumor thrombus (TT) infiltrates into the IVC wall and adheres densely to the endothelium, partial resection is needed [14]. When the TT has completely obliterated the IVC lumen and there is a simultaneous distal long bland thrombosis in the IVC, segmental resection should be performed [13, 14] Segmental resection often results in complex vascular reconstruction via vascular patch or interposition graft [15]. Predicting IVC invasion preoperatively would be advantageous for evaluating and planning surgical approaches and in patient consultation.

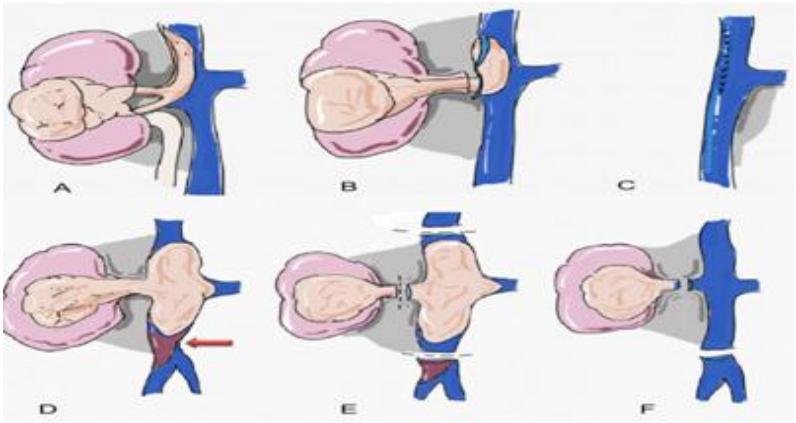

Fig1: *When tumor thrombus (TT) infiltrates into the inferior vena cava (IVC) vascular wall, IVC resection is necessary. (Fig.1A) partial resection the IVC involved by TT is needed(Fig.1B), and then suture of IVC. When the inferior vena cava tumor thrombus has completely obliterated the IVC and there is a simultaneous distal long bland thrombosis in the IVC (Fig.1D, arrow), segmental resection (Fig.1E) orinterruptment of IVC (Fig.1F) should be performed.*

Current classification systems for RCC with IVCTT, such as the Mayo clinic [16], Novick, and Hinman systems, only takes into account the location of the TT, which may be insufficient to intraoperatively evaluate the probability of invasion of the IVC [17]. Moreover, there is still no standard in classifying IVCTT on imaging [18]. Thus, IVC thrombectomy caused by IVC invasion often requires comprehensive preoperative imaging evaluation. At present, magnetic resonance imaging (MRI) is the first choice for diagnosing IVCTT [19, 20] However, when the IVC blood flow decreases below certain range due to tumor compression, the effect of slice saturation may lead to false positive diagnosis [21] Ultrasonography not only allows observation of the length and width of the IVCTT, but also provides hemodynamic information, including the blood flow of the IVCTT and venal lumen, in which case the IVC is compressed. Parameters from multiple imaging techniques could provide a more comprehensive tumor thrombus evaluation. Few studies have evaluated the potential factors predicting the need for IVC resection by combining ultrasound with MRI/computed tomography (CT) findings.

Our objective was to screen for such predictors from MRI/CT and ultrasonic images and establish an image prediction model to evaluate the probability of IVC invasion preoperatively.

2. Materials and Methods

We retrospectively reviewed 164 patients with RCC with IVCTT who underwent radical nephrectomy and IVC thrombectomy between January 2014 and April 2019. This study was approved by the institutional review board of the hospital involved. All patients had been preoperatively examined by ultrasound, CT, and /or MRI, and postoperative pathological analysis was performed for the cases either confirming RCC with tumor invasion of the IVC wall or not. Exclusion criteria included: level 0 IVCTT

(*n* = 28), incomplete imaging or pathology data (*n* = 18), recurrent patients (*n* = 3), and the inability to measure of IVC caused by IVC compression (*n* =3).The remaining 112 patients with Mayo I-IV IVCTT formed the analytical cohort for this study, and 86 patients were used to establish the imaging model, and data validation was performed in 26 patients. The study cohort and exclusion criteria were listed in Fig.2.

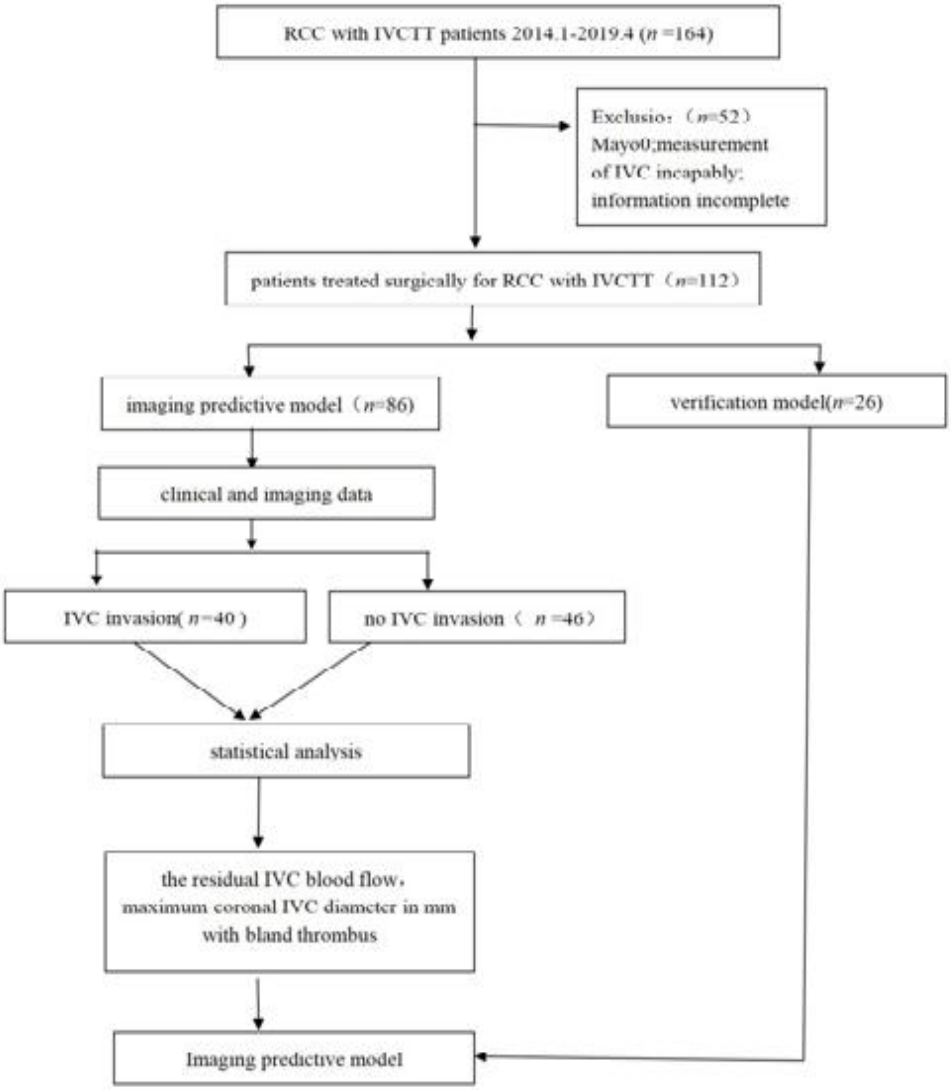

Fig2: *Summary of the study cohort and exclusion criteria*

2.1. Ultrasonography

Tran abdominal ultrasonography and IVC ultrasound examination were performed using Convex array probe C1-6MHz (LOGIQ E9, GE Healthcare, USA), C5-1MHz (EPIQ 7, Philips Ultrasound, USA), C5-1MHz (Hivision Ascend us, Hitachi, Japan), CA1-7AMHz (RS80A, Samsung Medison, Korea). For level IV TT exceeding the diaphragm, the cardiac ultrasound probes X5-1, S5-1 (EPIQ 7C, PHILIPS) and DM1-6A (RS80A, Samsung Medison, Korea) were used to observe the intra-atrial TT.

The patients were in the supine and lateral position to obtain clear images of the IVCTT. Two-dimensional, color and spectrum doppler was used to examine the IVCTT in detail. The length, echo, and color blood flow of the tumor embolus were recorded. All imaging data were archived in the electronic system of the ultrasound diagnostic department for subsequent analysis.

2.2. CT Scanning Sequence and Parameters

All patients received multidetector row CT (MDCT) (GE Revolution, GE Healthcare, USA) scan using CT apparatus and the energy spectrum scanning GSI Abd sequence. CT parameters were as follows: 80-140 kV/190 mA; layer thickness, 5 mm; pitch, 0.99; rotation time, 0.8 s; window width, 350 Hu; window level, 40 Hu; and matrix, 512 x 512. The upper

boundary included the right atrium. Iopromide (iodine concentration: 370 mg/mL, 1.4 mL/kg) was injected through the anterior elbow vein at a rate of 4 mL/s. When the CT value of the ascending aorta was 120 HU, enhancement scanning was performed: 10 s (arterial phase), 35 s (venous phase) and 50 s (delayed phase).

2.3. MRI Examination Sequences and Parameters

All MRI examinations were performed using a 3.0-T superconducting imaging system (Discovery MR750, GE Healthcare, and USA) and abdominal array coils. The scope of scanning included the upper and lower bounds of the ICVTT and the renal vain. The main MRI scanning parameters are listed in Table 1. Injection grade dimegluminegadopentetate (20 mL, 20 mL/9.39 g) or gadoteric acid melamine salt (15 mL, 377 mg/mL) were injected through the anterior elbow vein at a rate of 2-3 mL/s, at a dosage depending on the patient's weight (0.4mL per kgof patient's weight). Enhancement scanning was performed for 20 s (arterial phase) and 40 s (venous phase).

Table1: *Sequence parameters for IVCTT with abdominal array coils at 3.0-T superconducting imaging system*

	Imaging plane	Freq FOV[a]	Phase-FOV	TR/TE[b] (ms)	Slice thickness/ spacing(mm)	Band width (kHz)	flip angle (°)	NEX [c]	Time
T2 FS RTr propeller [d]	axial		36	9000/82	6.0/1.0	62.5			2min
T2 SSFSE[e]	sagittal	40	0.7	1028/70	6.0/1.0	62.5			18s BH [f]
	coronal	40	0.9	1216/70	6.0/1.0	62.5			22s
LAVA[g]Flex	axial	40	0.8	4.0/1.8	5.0	142.86			20s BH
LAVA-Flex 3	axial	36	0.8	4.0/1.8	5.0	142.86	10	1.0	1min
LAVA-Flex +C	sagittal	35	1	4.4/1.9	3.0	142.86	15	1.0	23s BH
	coronal								24s BH
DWI [h]	axial	35	1	4800/62	6.0/1.0	250			3min54s

FOV: field-of-view, TR: repetition time TE: echo time, NEX: number of excitations, FS: fat suppression RTr: Respiratory trigger, SSFSE: Single Shot Fast Spine Echo, BH: breath-hold, LAVA: Liver Acquisition with Volume Acceleration, DWI : diffusion-weighted imaging

2.4. Features of Patients with IVCTT

The clinical features included age, sex, the side of RCC, postoperative pathological diagnosis, IVCTT Mayo level, pathological type of RCC and vascular wall invasion. Multimodal image analysis included both ultrasound and MRI/CT scans. The residual blood flow of the IVC was assessed by ultrasound. Two doctors specialized in ultrasound, blinded to details of each patient's surgical procedure, and retrospectively analyzed the ultrasound blood flow images. Blood flow signals were labeled as 1 when existent and 0 when no blood flow is indicated from image.

Imaging data from MRI/CT were evaluated by one radiologist without the knowledge of the operation of the patients. Parameters of imaging in MRI/CT included: maximum anterior–posterior (AP) IVC diameter, IVCAP diameter at the renal vein ostium (RVo), maximum coronal IVC diameter, coronal IVC diameter at the RVo, contra lateral renal vein AP diameter at the RVo, maximum AP diameter of renal vein, AP diameter renal vein, bland thrombus presence in the IVC, and complete occlusion of the IVC at RVo.

2.5. Statistical Analysis

Categorical features are summarized with frequency counts and percentages, while continuous data are presented as the mean ± standard deviation. For categorical variables, comparisons were performed using the Pearson chi-square or Fisher exact tests. For continuous data, features were compared between groups using two-sample independent t-test.

Univariable associations of features with the need for IVC resection were evaluated using binary logistic regression to calculate the OR (odds ratio) and 95%, confidence interval(CI). The multivariable model was used stepwise selection by Backward(wald), and the P value leaved the model setting to 0.10, and best feature selection.

We used the Kappa statistic to calculate the reproducibility of the assessments provided by the ultrasound doctors. Statistical analysis was performed using SPSS IBM 23.0 (IBM, New York, USA). All tests were two-sided, and P values < 0.05 were considered to indicate statistical significance.

3. RESULTS

Among the 86 patients, 46.5% (40/86) the IVC wall were infiltrated. Univariable associations of clinical and radiographic features predicting the vascular invasion at the time of tumor thrombectomy are listed in Table 2. Radiographic imaging by MRI and/or CT showed that, compared to patients who were not invasion of vascular wall , those that predic the probability of IVC IVC wall invision: the residual IVC bloid invased vascular wall were significantly more likely to have distal bland thrombosis (P < 0.001),complete IVC occlusion at the RVo (P < 0.001), ultrasound imaging were significantly more likely to have no residual blood flow (P < 0.001) and a significantly larger maximum AP IVC diameter (36.3±5.6) mm vs. (29.2±4.8) mm., P< 0.001; IVC APdiameter at the RVo (30.6±5.7) mm vs. (25.7±6.7) mm,P< 0.001; maximum coronal IVC diameter (36.3±5.6) mm vs. (29.2±4.8) mm,P< 0.001.In the final multivariable mode (Table 3), three features were selected to predict the probability of IVC wall invasion: the residual IVC blood flow (OR 0.170; P = 0.007) , maximum coronal IVC diameter in mm (OR 1.203; P= 0.003)and with bland thrombus (OR 3.216; P=0.080) . Combining these three features, we found that the area under the curve (AUC) of the receiver operating characteristic (ROC) was 0.889(Fig. 3).

Table2: *Univariable associations of multimodal image parameters predicting vascular wall invision*

Features	**IVC invasion**			
	Yes (*n* = 40)	**No (*n*= 46)**	***t/χ2***	***P***
	$\bar{x} \pm s$			
Age , y	58.6± 11.0	58.5 ± 12.7	0.280	0.985
Maximum IVCAP diameter, mm	36.3 ± 5.6	29.2 ± 4.8	0.293	< 0.001
IVC APdiameter at the RVo, mm	30.6 ± 5.7	25.7± 6.7	0.156	< 0.001
Maximum coronal IVC diameter, mm	36.3± 5.6	29.2 ± 4.8	2.117	< 0.001
Coronal IVC diameter at the RVo, mm	35.2 ± 5.5	28.7± 5.0	0.830	< 0.001
Contralateral renal vein APdiameter at the RVo, mm	10.6± 3.49.4 ± 2.2		2.954	0.510
MaximumAP diameter of renal vein	21.9± 5.221.7 ± 5.6		0293	0.867
AP diameter renal vein	20.5± 5.419.0 ± 5.2		0.147	0.204
		n (%)		
Sex			3.958	
Male	30(75.0)	25(54.3)		
Female	10(25.0)	21(45.7)		
Side			0.006	1.000
Right	29(72.5)	33(71.7%)		
Left	11(27.5)	13(28.3%)		
Tumor thrombus level			10.471	0.015
Mayo I	3(7.5)	14(30.4)		
Mayo II	16(40.0)	20(43.6)		
Mayo III	14(35.0)	6(13)		
Mayo IV	7(17.5)	6(13)		
Pathological type			2.036	0.361
Clear cell renal cell carcinoma	28(70.0)	38(82.6)		
Papillary renal cell carcinoma	7(17.5)	4(8.7)		
Other	5(12.5)	4(8.7)		
Vascular wall invasion by pathological examination			5.070	0.031
No	26(65.0)	39(84.8)		
Yes	12(30.0)	5(10.9)		
Unsure	2(5.0)	2(4.3)		
Bland thrombus in the IVC on CT/MRI			19.822	< 0.001
No	15(62.5)	39(84.8)		
Yes	25(37.5)	7(15.2)		
Complete IVC occlusion at the RVo on CT/MRI			12.825	< 0.001
No	5(12.5)	21(45.7)		
Yes	34(80.5)	21(45.7)		
Unsure	1(2.5)	4(8.6)		
Residual IVC blood flow on ultrasound			19.873	< 0.001
No	33(82.5)	16(34.8)		
Yes	7(17.5)	30(65.2)		

Table3: *Multivariable associations of multimodal image parameters predicting IVC wall invision*

Features	Univariate analysis OR (95% CI)	*P*	Multivariable analysis OR (95% CI)	*P*
Maximum IVC APdiameter, mm	6.580(3.295-9.865)	< 0.001		
IVC APdiameter at the RVo, mm	1.181(1.081-1.290)	< 0.001		
Residual IVC blood flow	0.477 (0.288-0.666)	< 0.001	0.170（0.047-0.611）	0.007
Maximum coronal IVC diameter, mm	7.101(4.887-9.314)	< 0.001	1.203（1.0651.360）	0.003
Coronal IVC diameter at the RVo, mm	6.489(4.219-8.753)	<0.001		
Bland thrombus in the IVC on CT/MRI	0.473(0.289-0.656)	< 0.001	3.216（0.87011.887）	0.080
Complete IVC occlusion at the RVo on CT/MRI	0.372(0.180-0.564)	< 0.001		

OR, odds ratio; CI, confidence interval; AP, anterior-posterior; IVC, inferior vena cava; IVCTT, IVC tumor thrombus; RVo, renal vein ostium; CT/MRI, computed tomography/magnetic resonance imaging;

Table4: *Multivariable model to predict IVC wall invision*

	B	OR (95% CI)	*P*
Residual IVC blood flow	-1.770	0.170(0.047-0.611)	0.007
Maximum coronal IVC diameter	0.185	1.203(1.065-1.360	0.003
Bland thrombus	1.168	3.216(0.870-11.887	0.080
Constant	-5.857	0.000	

IVC, inferior vena cava; B, regression coefficient; OR, odds ratio; CI, confidence interval

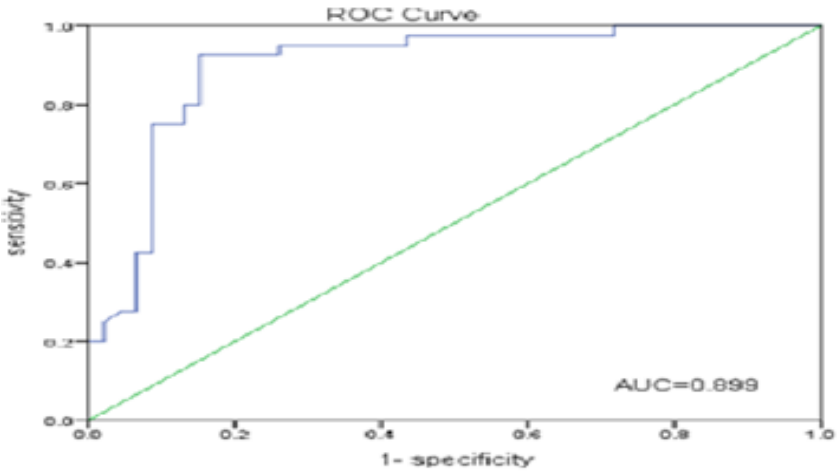

Fig3: *Receiver operating characteristic (ROC) curve analysis of predicted probabilities of invasion of inferior vena cavawal (IVC) wall invision according to the combine with the three features: maximum coronal IVC diameter; residual IVC blood flow on ultrasound and with bland thrombus. Area under Curve (AUC) of ROC is 0.899.*

The final model to predict the need for IVC invision is summarized as follows (see also Table 4):

$$Ln\{\frac{pre}{1-pre}\} = 0.185 \times \max imum\ cornal\ IVC\ diameter + 1.168 \times bland\ thrumbus$$

$$-1.770 \times residual\ IVC\ blood\ \ flood\ -5.857$$

Where the residual IVC blood flow variable is 1 or 0 and 'pre' is the probability of IVC vascular wall invision. Thus, we could calculate the probability of IVCinvision (Fig. 4). A probability＜50% indicated without IVC vessel wallinvision. A probability＞50% indicated IVC vessel wallinvision. Among all patients, the predicted invision probability was consistent with the actual operation in 89.5% (77/86) but opposite in 10.5% (9/87) of the cases. The false positive rate was 3.5% (3/86), and the false negative rate was 7.0% (6/86).

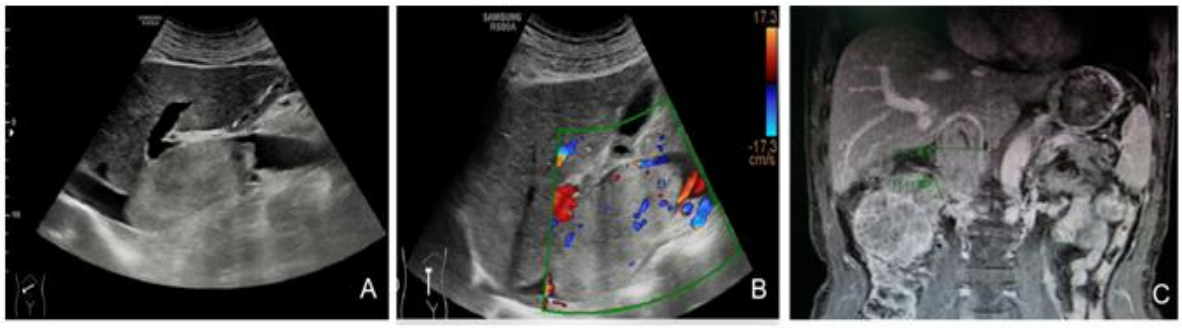

Fig4:*Imaging and pathological findings in a 63-year-old male with clear cell renal cell carcinoma (ccRCC) in the right kidney with inferior vena cava (IVC) tumor thrombus (IVCTT, Mayo III). (A) Ultrasound images showing that the IVC is completely obstructed and has no residual blood flow. (B). Coronal gadolinium enhanced T1-weighted image showing the IVCTT and its maximum coronal diameter of 37.5 mm. The possibility of IVC resection was 74% in this case. In consideration of tumor invasion of IVC wall, so IVC resection was performed.*

In the literature, a strong interobserver concordance and reproducibility regarding measurements of vascular diameters on MRI scans has been confirmed, ranging from 0.93 to 0.99 [21]. In this study, we assessed the concordance correlation coefficient for estimating blood flow in the residual lumen using two sonographers. The kappa of the blood flow in the residual lumen was 0.77; therefore, the diagnostic results provided by the ultrasound doctors were consistent.

4. DISCUSSION

Renal carcinoma is a common malignant tumor of the urinary system. IVCTT occurs in4-10% of the RCC cases [21] Radical nephrectomy and IVC thrombectomy can effectively improve the prognosis of locally advanced RCC, with a disease-specific survival rate of 40 to 60% at 5 years [22,23]. A previous study reported that 6-8% of patients undergoing tumor thrombectomy required segmental excision of the IVC [13]. The objective of surgical treatment for RCC with IVCTT is to completely remove all tumor burdens. Therefore, it is necessary to remove the vascular wall that inflitrated by IVCTT. However, IVC infiltrated by IVCTT is a risk factor for poor prognosis [24] and an improtant factor for IVC resection. Thus, comprehensive preoperative imaging evaluation may allow urologist surgeons to treat the IVC more effectively [22, 25].

Our data showed that 46.5% (40/86) patients IVC invision. Using univariate and multivariate analysis, we identified three strong indicators and significant risk factors for IVC invision: the coronal maximum IVC diameter in MRI/CT and the absence of color flow signal in ultrasound and with bland thrombus.

Previous research on IVCTT has suggested that the most tolerable invasion area of the IVC wall is the RVo [13]. The IVC diameter at the RVo can be used to predict IVC resection and the invasion in the IVC wall. Psutka et al. [13] indicated that previous literature had not reported the endpoint for the need of IVC resection or potential complex IVC reconstruction caused by IVC invision. Their studies also showed that Mayo Clinic risk factors in radiologic findings consist of three features, while Overholseret al [26] reported that these factors could not predict IVC vascular invasion and reconstruction. Similar to these studies, we found that the maximum coronal IVC diameter is a risk factor for IVC resection. The data showed that, in 89.5% (77/86) of the cases, this diameter was the same as the coronal diameter of the renal vein at the RVo, which was closer to the proximal part of IVC; however, the two diameters were different in 12.9% (11/86) of the cases. This may be related to the kinetics of tumor invasion and metastasis. Cancer cells invade tissues through two mechanisms: growth-related tumor expansion and cancer cell locomotion. Tumor growth generates expansive forces that tend to push the tumor along paths of least resistance [27].And 82% (9/11) were classified as WHO/ISUP 2016 nuclear grade III-IV. This might explain why, in some patients, the maximum coronal IVC diameter was different from that of the renal vein at the RVo that is closer to the proximal part. The underlying mechanism needs further investigation; nevertheless, our results suggest that attention should not only be paid to the IVC at the RVo but also to its maximum coronal diameter.

Another imaging parameter of the predictive model is that the residual IVC blood flow in

ultrasound, which is a protective factor for the invasion of IVC wall. Psutka. [13] et al. analysis showed that one of the risk factors for IVC resection was complete obstruction of IVC at the RVo. The residual IVC blood flow in ultrasound was detected, which indicated that there was a space in the IVC and the lumen of IVC has not been completely obstructed by tumor thrombus. In addition, we think the flow and scouring of blood flow the residual IVC blood flow can prevent cancer cells from adhering to the wall of the vascular and hinding the formation of tumor thrombus.

Previous studies have focused on IVC by using MRI / CT images, but there is limited research on the evaluation of IVCTT by ultrasound. It is difficult to assess the presence of IVCTT by MRI when the IVC is compressed by large tumors and enlarged lymph nodes. The results false positivity of MRI can be seen when the blood flow of IVC decreases, the flow velocity slows down and the saturation effect is obvious [28]

The advantage of ultrasound is that it can display blood flow signals dynamically in real time. Ultrasound can detect blood flow signals in the residual lumen, which indirectly proves that IVC lumen is not completely obstructed. At the same time, through adjusting the parameters, ultrasound can display the low-velocity blood flow well, and remedy the misdiagnosis of MRI/CT caused by the pressure of the lumen and the decrease of flow velocity, and increase the accuracy of evaluating IVC invasion.

The third predictor of IVC invasion was bland thrombus at the distal of the IVC. Catalane al [29] retrospectively analyzed the causes of bland thrombus in patients of cancer, because of the Virchow triad in the cancer patient’s such as: endothelial injury, stasis of flow caused by vascular infiltration by tumor mass or blood hyper viscosity, activation of clotting, in patients with RCC and IVCTT, bland thrombus is often accompanied by tumor thrombus, especially local progressive RCC. Hutchinson [14] etalanalyzed 446 patients with radical nephrectomy with thrombectomy in five medical centers to study the effect of bland thrombus (mainly composed of activated platelets, macrophages and fibrin) on their survival, and the increase of cancer-specific mortality (CSM) in patients with thrombosis. Besides, studies on RCC have shown that RCC of immunoreactivity could affect the tumor aggressive behavior, and enhanced immune surveillance. Immune surveillance may lead to hypercoagulability, which may be easy to form bland thrombus [14]

The influence of bland thrombus on operation is related to the establishment of collateral circulation, and the length of bland thrombus, which decides the magement of the IVC. 50% patients with bland thrombus require IVC segmental resection or partial resection, which is a potential challenge for surgeons.

Importantly, we developed a multivariable model to predict the need for IVC invasion combining the maximum coronal IVC diameter and residual IVC blood flow on ultrasound and with bland thrombus. The AUC of the ROC curve was 0.889, so the model proved to exhibit great predictive value. The predicted resection probability was consistent with the actual operation in 89.5% (77/86) of the patients. Thus, this model may be used for preoperative planning and for individually calculating the resection probability for each patient.

This study has some limitations due to its retrospective nature, leading to a potential selection bias. Moreover, the reference standard of wall invasion was used as intraoperative findings. In addition, it presents a single institution's clinical experience and practice patterns; thus, a multicenter validation would be needed. In the future, more cases should be examined to verify our prediction model.

5. Conclusions

We identified the coronal maximum IVC diameter in MRI/CT, color flow signal absence in ultrasound and with bland thrombus as three key parameters of multimodal imaging associated with IVC invision. Our prediction model can be used during preoperative planning to evaluate and predict the probability of partial or segmental IVC resection.

Acknowledgments

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