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World Journal of *Radiology*

Contents

Contents

ABOUT COVER

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AIM AND SCOPE

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EDITORIAL

Advances of multidetector computed tomography in the characterization and staging of renal cell carcinoma

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Abstract

Renal cell carcinoma (RCC) accounts for approximately 90%-95% of kidney tumors. With the widespread use of cross-sectional imaging modalities, more than half of RCCs are detected incidentally, often diagnosed at an early stage. This may allow the planning of more conservative treatment strategies. Computed tomography (CT) is considered the examination of choice for the detection and staging of RCC. Multidetector CT (MDCT) with the improvement of spatial resolution and the ability to obtain multiphase imaging, multiplanar and three-dimensional reconstructions in any desired plane brought about further improvement in the evaluation of RCC. Differentiation of RCC from benign renal tumors based on MDCT features is improved. Tumor enhancement characteristics on MDCT have been found closely to correlate with the histologic subtype of RCC, the nuclear grade and the cytogenetic characteristics of clear cell RCC. Important information, including tumor size, localization, and organ involvement, presence and extent of venous thrombus, possible invasion of adjacent organs or lymph nodes, and presence of distant metastases are provided by MDCT examination. The preoperative evaluation of patients with RCC was improved by depicting the presence or absence of renal pseudocapsule and by assessing the possible neoplastic infiltration of the perirenal fat tissue and/or renal sinus fat compartment.

Core tip: Multidetector computed tomography (MDCT) remains the most widely available and most effective modality for the detection and staging of renal cell carcinoma (RCC), with a staging accuracy up to 91%. MDCT scanners with the improvement of spatial resolution and the ability to obtain multiplanar and 3D-reconstructions greatly improved the diagnostic performance of CT in characterizing RCC and estimating the extent of the disease. Important information for treatment planning is provided by CT examination, including tumor location and size, renal arterial and venous anatomy and relationship to the pelvicaliceal system.

INTRODUCTION

Renal cell carcinoma (RCC) represents the commonest primary malignancy of the kidney, accounting for about 2%-3% of all cancers[1-3]. In 2012, approximately 84400 new cases of RCC were diagnosed within the European Union and 34700 kidney cancer-related deaths occurred[2]. The estimated number of new cases of kidney cancer in the United States during 2014 was 63920, the great majority representing RCCs, accounting for the seventh most common malignancy in men and the 12th commonest malignancy in women[3]. An estimated 13860 deaths from kidney cancer were expected to occur in 2014[3].

The widespread use of cross-sectional imaging modalities has resulted in incidental detection of more than 50% of RCCs[1-4]. These tumors are often small, of low stage and grade, and therefore have a better prognosis[1-4]. Early-stage RCC is usually asymptomatic. The classic clinical triad of flank pain, gross haematuria, and palpable abdominal mass is not common (6%-10% of cases) and usually correlates with aggressive histology and advanced-stage disease[1,5,6]. There is a 1.5:1 predominance in men over women, with a peak incidence occurring during the 6th and 7th decades of life. The main predisposing factors for renal cancer are smoking, obesity, hypertension, chronic renal failure, chemical exposure and radiation exposure[1-3]. Heredity also plays a role, with approximately 4% of all RCCs seen in patients with an underlying tumor syndrome[7,8].

In patients with RCC, tumor stage at diagnosis, nuclear grade according to Fuhrman, and histologic subtype represent the most important prognostic factors[1]. Tumor stage greatly affects patient's prognosis and survival, and has an important impact on treatment planning. The tumor, node, metastasis (TNM) staging classification system is most commonly used, closely correlating with potential curability of the disease and prognosis[1,9]. The latest version of the TNM classification was published in 2010[1,9] and is presented in Table 1.

The grading classification of RCC is based on the microscopic characteristics of the neoplasm with hematoxylin and eosin staining. Fuhrman nuclear grade is the most widely accepted histological grading system for RCC[10]. Although affected by intra- and inter-observer discrepancies, it represents one of the most significant prognostic variables in patients with all stages of RCC[10-13]. This system categorizes RCC with grades 1, 2, 3, and 4, varying from tumors with small, round hyperchromatic nuclei, no visible nucleoli and little detail in the chromatin to those with larger, pleomorphic nuclei, single or multiple macronucleoli and coarsely granular chromatin[10]. Some researchers have simplified the Fuhrman grading system in order to improve interobserver reproducibility. More specifically, a modified two- or three-tiered Fuhrman grading system could probably have a virtually equal accuracy as the conventional 4-tiered Fuhrman grading system in predicting cancer-specific mortality[11-13].

The 2004 World Health Organization classification for renal neoplasms recognizes several distinct histologic subtypes of RCC, of which three main types are important: conventional (clear cell) RCC (ccRCC, accounting for approximately 80%-90% of RCCs); papillary RCC (10%-15%); and chromophobe RCC (4%-5%)[14,15]. In univariate analysis, there is a trend towards a better prognosis for patients with chromophobe vs papillary vs conventional RCC[16,17].

The 5-year overall survival for all types of RCC is 49%. More than half of cases are diagnosed at early-stage, for which the 5-year relative survival rate is 92%[1].

Radical nephrectomy with ipsilateral adrenalectomy, as established by Robson, was the treatment of choice since 1969[1]. During the last decades, there is a growing trend for more limited surgical resection, such as adrenal-sparing radical nephrectomy, laparoscopic nephrectomy, or nephron-sparing partial nephrectomy[1-4,18-24]. Partial nephrectomy can be performed, either with an open, pure laparoscopic or robot-assisted approach, based on surgeon's expertise and skills. Similar oncological outcomes have been reported for both nephron-sparing surgery (NSS) and radical nephrectomy[1,22-24]. NSS is primarily recommended in patients with T1a tumors, and when technically feasible in T1b neoplasms[1]. Non-surgical treatment, including ablative techniques such as cryoablation, and radiofrequency ablation have been proposed for RCCs less than 4 cm in diameter[1,25]. However, due to the low quality of the available data no published recommendations still exist on these techniques[1]. Active surveillance may be offered to some patients, especially in elderly and/or comorbid patients with small renal tumors[26,27].

ROLE OF COMPUTED TOMOGRAPHY

Computed tomography (CT) is widely accepted as the examination of choice for the detection, characterization and staging of RCC, with a staging accuracy up to 91%[4,28-47]. The wide availability of CT and its relative ease of performance and interpretation compared with magnetic resonance imaging (MRI) render it the main imaging method for staging RCC. In surgical cases, accurate preoperative imaging and exact tumor staging is of paramount importance for planning the optimal surgical approach and strategy, and for providing accurate prognostic information for the patient. Knowledge of the renal and tumor vascular supply and the relationship of the neoplasm to the adjacent renal

Table 1 New tumor, node, metastasis classification system for renal cell carcinoma			
T-primary tumor			
Tx	Primary tumour cannot be assessed		
T0	No evidence of primary tumour		
T1	Tumour ≤ 7 cm in greatest dimension, limited to kidney		
T1a	Tumour ≤ 4 cm in greatest dimension, limited to kidney		
T1b	Tumour > 4 cm but ≤ 7 cm in greatest dimension, limited to kidney		
T2	Tumour > 7 cm in greatest dimension, limited to kidney		
T2a	Tumour > 7 cm but ≤ 10 cm in greatest dimension, limited to kidney		
T2b	Tumour > 10 cm in greatest dimension, limited to kidney		
T3	Tumour extends into major veins or perinephric tissues but not into the ipsilateral adrenal gland and not beyond Gerota fascia		
T3a	Tumour grossly extends into the renal vein or its segmental branches, or tumour invades perirenal and/or renal sinus fat but not beyond Gerota fascia		
T3b	Tumour grossly extends into the vena cava below the diaphragm		
T3c	Tumour grossly extends into the vena cava above the diaphragm or invades the wall of the vena cava		
T4	Tumour invades beyond Gerota's fascia (including contiguous extension into the ipsilateral adrenal gland)		
N-regional lymph nodes			
Nx	Regional nodes cannot be assessed		
N0	No regional lymph nodes metastases		
N1	Metastases in a single regional lymph node		
N2	Metastases in more than 1 regional lymph node		
M-distant metastases			
M0	No distant metastases		
M1	Distant metastases		
TNM stage grouping			
Stage Ⅰ	T1	N0	M0
Stage Ⅱ	T2	N0	M0
Stage Ⅲ	T3	N0	M0
	T1,T2,T3	N1	M0
Stage Ⅳ	T4	Any N	M0
	Any T	N2	M0
	Any T	Any N	M1

TNM: Tumor, node, metastasis.

parenchyma and the pelvicaliceal system are crucial for operative planning, particularly in patients planned for NSS[48-51].

According to the recommendations by the American College of Radiology, multidetector, multiphasic CT of the abdomen is considered appropriate for staging of small or incidentally detected renal tumors (equal or smaller than 3 cm in diameter)[52]. For renal tumors larger than 3 cm in diameter, multidetector CT (MDCT) is the diagnostic modality of choice. MRI of the abdomen is a suitable substitute, when patient cannot undergo contrast-enhanced CT. Ultrasonography may be considered more appropriate for staging small renal tumors, when the intravenous administration of contrast medium is contraindicated. Positron emission tomography (PET) does not yet have an established role in staging RCC. PET with the tracer fluorine-18-2-fluoro-2-deoxy-D-glucose-PET may find difficulties even in the detection of primary carcinoma against the normal background of hyperactivity in the kidneys. PET may be used as a complementary examination for confirming metastatic disease in lesions detected by CT, MRI, or bone scan, and it may be used to detect unsuspected metastases in high-risk patients[52].

The most recent technical advances introduced with the use of MDCT scanners brought about further advancements in the preoperative evaluation of RCC[4,31-51]. The main advantages of MDCT are fast scanning time, increased volume coverage, acquisition of thin slices and improved spatial and temporal resolution. Rapid coverage of the kidneys and scanning during specific organ perfusion phases after the intravenous administration of iodinated contrast material has improved the diagnostic performance of CT in the detection and characterization of renal masses[34-41]. The use of thin slices and the acquisition of near-isotropic or isotropic data improve the quality of volume data set for workstation analysis and multiplanar reformations (MPRs) and 3D reconstructions in any desired plane with excellent anatomic details are possible[30-33,49-51].

MDCT protocol
MDCT examination in cases of a known or suspected renal mass should include multiple phases, proper timing of each post-contrast enhanced phase, and use of MPRs and 3D-reconstructions. The CT protocol includes an unenhanced acquisition, combined with two or more post-contrast enhanced series (corticomedullary phase, nephrographic phase, and excretory phase)[4,28-47].

Figure 1 The 65-year-old woman with papillary renal cell carcinoma of the right kidney and tumoral invasion of the ipsilateral renal vein and the inferior vena cava (stage T3b, grade 2). The patient had left radical nephrectomy years ago for renal cell carcinoma. A: Transverse unenhanced computed tomography (CT) image shows a lobular right renal mass (arrowhead), located in the interlobar region. The mass is relatively homogeneous, slightly hyperdense (CT density: 40 HU), when compared to the normal renal parenchyma; B and C: Contrast-enhanced coronal multiplanar reformations during the corticomedullary phase depict right renal tumor, with moderate, homogeneous enhancement (arrowhead, mean CT density: 65 HU). Venous tumour thrombus is diagnosed as a filling defect within right renal vein and the infrahepatic part of the inferior vena cana (arrow). Neoplastic thrombus is seen extending directly from the neoplasm, enhancing with a similar pattern with primary malignancy.

The unenhanced scanning is always necessary to serve as a baseline for measurements of enhancement after contrast material administration. Areas of hemorrhage and/or presence of calcifications are also seen on these images. In the corticomedullary phase, obtained 25-70 s after the start of injection, an intense enhancement of the renal cortex is observed, while the medulla does not enhance and remains hypodense. This phase is essential for staging RCC. An accurate diagnosis of venous

Figure 2 The 70-year-old man with clear cell renal cell carcinoma of the left solitary functioning kidney (stage T1b, grade 2). A: Post-contrast enhanced coronal multiplanar reformation during the corticomedullary phase depicts left upper pole renal mass, strongly and heterogeneously enhancing, after contrast material administration. A thin hyperdense rim (arrowheads) is detected around the tumor, proved to correspond to fibrous pseudocapsule on pathology. Atrophic right kidney (arrow); B: Coronal 3D-reconstruction during the same phase, using maximum intensity projection algorithm shows left renal artery aneurysm (arrow).

extension of tumoral tissue is possible (Figure 1). This phase may be also used as a map for the delineation of the arterial anatomy of the kidneys (Figure 2), especially helpful in selected cases to plan NSS. Hypervascular arterialized metastases from RCC may be more evident on this phase (Figure 3). The nephrographic phase, with a delay of 80-180 s after contrast administration is considered the most important for detecting and characterizing renal tumors. During this phase, normal renal parenchyma enhances homogeneously, allowing the best opportunity for the delineation of renal masses, which are often detected with relatively less contrast enhancement (Figure 4). The excretory phase is acquired after a 4-8 min delay, resulting in excretion of contrast material into the pelvicaliceal system. The relationship of the tumor to the renal collecting system (Figure 5) and possible signs of invasion are evaluated in this acquisition.

In addition to multiphase imaging, multiplanar display techniques, including MPRs and 3D-reconstructions, more often with maximum intensity projection and volume rendering technique are essential and improve the diagnostic performance of CT in detecting, characterizing and staging of RCC[28-33,48-51]. MPRs and 3D-reconstructions can be viewed in multiple planes and orientations, providing a useful interctive road map when planning treatment, either surgery or conservative. Accurate depiction of the position of the kidney relative to the

Figure 3 The 52-year-old man with advanced-stage clear cell renal cell carcinoma of the right kidney. Contrast-enhanced (A) coronal and (B and C) sagittal reformations during the corticomedullar phase show a large right renal tumor (arrow), strongly and inhomogeneously enhancing. Central hypodense parts within malignancy corresponded to areas of necrosis on histology. There is perinephric stranding and contrast-enhancing nodules in the perinephric fat (long arrow, B), a finding strongly suggestive for perinephric fat invasion. The tumor is seen extending and invading the undersurface of the liver (long arrow, C). Lung metastases are detected (arrowheads, A and C). There is also a small amount of ascites and nodular peritoneal masses (arrowheads, B), with heterogeneous enhancement, identical to that of the primary neoplasm, findings suggestive of peritoneal metastases. Peritoneal metastases from renal cell carcinoma (RCC) are extremely rare. Neoplastic invasion of the peritoneum by RCC may occur either, by contiguous spread of renal tumor through the renal capsule, the anterior renal fascia and the posterior parietal peritoneum, or *via* tumoral emboli.

Figure 4 The 62-year-old man with clear cell renal cell carcinoma of the left kidney (stage T1a, grade Ⅱ). A: Transverse plain computed tomography image barely depicts lower pole left kidney mass (arrow), slightly hyperdense. This finding was appreciated after studying the post-contrast enhanced images; B: Coronal reformations during the corticomedullary; C: The nephrographic phase. The tumor (arrow) is seen enhancing strongly and heterogeneously during the corticomedullary phase, a finding strongly suggestive for the diagnosis of renal cell carcinoma (RCC). Hypervascular RCCs as in this case, may enhance to the same degree as the renal cortex and may be mistaken for normal renal parenchyma at the corticomedullary phase. The neoplasm is clearly delineated in the nephrographic phase, detected mainly hypodense, when compared to the contrast-enhancing normal renal parenchyma.

surrounding bones is helpful in guiding the initial surgical incision. Delineation of tumor location and depth of extension into the kidney, ensures maximal preservation of the surrounding normal renal parenchyma after surgery (Figure 6). The arterial and venous anatomy of the kidney is clearly depicted at 3D-CT angiography (Figure 2). Identification of renal vessels, possible anatomic variants and depiction of their relationship with the neoplasm may help minimize ischemic injuries and intraoperative complications. Depiction of the relationship of RCC to the collecting system and assessment of possible neoplastic infiltration represent valuable information in treatment planning, especially in cases of conservative surgery. The pelvicaliceal system is best visualized on coronal MPRs and volume rendering 3D-displays, with images closely resembling those of conventional intravenous urography[47-51].

CT findings of RCC

Most RCCs are solid tumors with CT density of 20 HU or greater at unenhanced scanning[4,28-33]. The tumor may not be clearly visible on plain images, because its density is usually similar to that of the surrounding normal renal parenchyma. In these cases, a focal bulging of the renal contour (Figure 7) may raise the suspicion of a space-occupying lesion. Small tumors (smaller than 3 cm in diameter) are usually homogeneous, while larger lesions tend to be more heterogeneous due to the presence of central necrosis and/or hemorrhage (Figures 3 and 5). Calcifications are seen in up to 30% of RCCs (Figure 5A).

RCC typically has a rich vascular supply[4,28-33]. Therefore, the hallmark diagnosis of RCC is the presence of strong, mainly heterogeneous contrast enhancement (Figures 2-6 and 8). A contrast enhancement value of more than 20 HU with respect to the noncontrast scan is

Figure 5 The 62-year-old man with clear cell renal cell carcinoma of the left kidney (stage T3a, grade 3). A: Transverse unenhanced computed tomography (CT) image shows large heterogenous left renal mass, with small areas of calcifications (long arrow); B: Transverse multiplanar reformation (MPR) during the corticomedullary phase demonstrates left renal malignancy (arrow), inhomogeneously enhancing. The left renal vein is dilated and enhances heterogeneously (arrowhead) due to neoplastic invasion. VTT enhances with a same pattern as renal cell carcinoma; C: Coronal reformations during the corticomedullary phase depicts tumor ill-defined margins and extension into the perinephric fat tissue (arrow). Thickening of the diaphragms of the perinephric space is also seen; D: Coronal MPR during the excretory phase shows nonvisualization of the upper calyces and invasion of the middle calyceal group (arrow), a finding strongly suggestive of invasion of renal sinus fat. CT findings were confirmed both surgically and pathologically.

considered suspicious for malignancy. An enhancement value between 10 and 20 HU, is considered intederminate[45]. On the nephrographic phase, RCCs typically appear hypodense compared to the normally enhancing renal parenchyma (Figure 4).

DIFFERENTIATION OF RCC FROM BENIGN RENAL TUMORS

The wide use of cross-sectional imaging studies has also led to an increase of incidentally discovered benign renal masses, including angiomyolipoma (AML) and renal oncocytoma. Because radical nephrectomy is not desirable for a benign tumor, the accurate characterization of renal masses is required to avoid unwanted surgery. CT findings may prove helpful in characterizing the nature of renal tumors[53-62].

AML can be accurately diagnosed on CT, by detecting the intratumoral fat component with negative density on unenhanced scanning. However, in approximately 4.5% of all AMLs intratumoral fat cannot be visualized at CT. Kim *et al*[53] in a retrospective study of 19 AMLs with minimal fat and 62 RCCs on two-phase helical CT, reported that homogeneous tumor enhancement and prolonged enhancement pattern were the most valuable CT findings in differentiating these tumors, more often

detected in the first group. Hyperdensity of a renal mass on plain CT images is another CT finding reported for AML with minimal fat[54]. Zhang *et al*[56] in a retrospective study of 44 AMLs with minimal fat and papillary RCCs reported that the unenhanced CT density, the presence of intratumoural vessels, and the CT density of early excretory phase images may be used to differentiate these tumors. Woo *et al*[57] reported unenhanced tumor-kidney CT density difference and long-to-short axis ratio as the simplest and more accurate features in differentiating AMLs with minimal fat from non-clear cell RCCs on three-phase MDCT.

Several studies have described CT imaging features of renal oncocytoma, including well-defined margins, homogeneous contrast enhancement, presence of a central stellate scar, spoke-wheel pattern of arterial enhancement and absence of hemorrhage, calcifications and necrosis[58,59]. More specifically, renal oncocytoma has been described as a sharply-demarcated solid homogeneous mass, with homogeneous contrast enhancement, except for a hypodense stellate, central area. However, these classic findings do not always allow a confident characterization of this tumor, because they are often seen in patients with RCC[58,59]. MDCT improved the diagnostic performance of CT in differentiating these tumors[60-62]. The enhancement and washout values

Figure 6 The 74-year-old man with synchronous bilateral renal cell carcinomas of clear cell type (stage T1). Bilateral synchronous renal cell carcinomas (RCCs) are uncommon, reported in less than 2% of patients with RCCs. The patient had left radical nephrectomy and right partial nephrectomy. Sagittal multiplanar reformations (MPR) (A) and coronal 3D reformation with volume rendering technique (B) during the corticomedullary phase depict a sharly-demarcated tumor in the lower pole of the left kidney (arrow, A), strongly and heterogeneously enhancing. Sagittal (C) MPR and (D) 3D reformation with the same algorithm depict a second, smaller tumor in the upper pole of the right kidney, with a similar pattern of contrast enhancement. Preoperative information obtained with computed tomography examination enabled conservative surgery for the right renal malignancy.

Figure 7 The 60-year-old woman with clear cell renal cell carcinoma of the left kidney (stage T1a, grade Ⅱ). A: Transverse plain computed tomography (CT) image depicts lower pole right renal mass as a focal bulging of the renal contour (arrow), mainly isodense (CT density: 35 HU) to the renal parenchyma; B: Axial multiplanar reformation during the corticomedullary phase clearly shows renal malignancy (arrow) moderately and heterogeneously enhancing (mean CT density: 60 HU). Heterogeneous contrast enhancement on imaging should always suggest renal malignancy preoperatively.

in MDCT may aid in distinguishing small oncocytomas from RCCs of similar size[60,61]. Bird *et al*[60] reported that early phase enhancement greater than 500% and washout values of greater than 50% were mostly seen in renal oncocytomas. Kim *et al*[62] reported characteristic contrast enhancement patterns for renal oncocytomas smaller than 4 cm in diameter on MDCT. The authors assessed segmental enhancement inversion during the corticomedullary phase and early excretory phase, defined as follows: in a renal mass showing two parts with different degrees of enhancement during corticomedullary phase, the relatively more enhanced part became less enhanced during early excretory phase, whereas the less-enhanced part during corticomedullary phase became highly enhanced during early excretory phase. Segmental enhancement inversion was found to be characteristic of small renal oncocytomas in this study[62].

Figure 8 The 75-year-old man with clear cell renal cell carcinoma of the right kidney, invading the liver. A: Axial plain image shows right heterogeneous right renal tumor (arrowhead); B: Transverse reformation during the corticomedullary phase depicts strong, heterogeneous mass enhancement. The tumor (arrowhead) enhances mainly in the periphery, with a mean computed tomography density of 110 HU (compared to that of 40 HU on the unenhanced images), a finding more compatible with the diagnosis of renal cell carcinoma of the clear cell variety. Central non-enhancing areas corresponded to areas of necrosis on pathology; C: Coronal reformation during the same phase shows renal tumor invading the liver (small arrows), a finding confirmed both on surgery and histopathology.

HISTOLOGIC CHARACTERIZATION OF RCC

RCC is considered a clinicopathologically heterogeneous disease and is classified into clear cell (conventional), papillary, chromophobe, collecting duct carcinoma, medullary carcinoma, and unclassified type[15-17]. The commonest histologic subtypes are clear cell, papillary, and chromophobe, accounting for 70%-80%, 14%-17%, and 4%-8% of RCCs, respectively. Each subtype is associated with a different prognosis. Clear cell RCC has the worst prognosis, with a 5-year survival rate of 44%-69%, when compared to the 5-year survival rate of 82%-92% for papillary RCC and the 5-year survival of 78%-87% for chromophobe RCC[15-17]. It has been proposed that a preoperative characterization of the histologic type of RCC may lead to improvements in predicting tumor response to treatment, in providing patient counseling, and in individualizing follow-up regimens[16,17].

CT findings have been reported to correlate closely with the histopathologic characteristics of the more common types of RCC[63-73]. Among CT criteria, degree of enhancement proved to be the most valuable parameter[63-69]. More specifically, ccRCCs are more often detected as highly hypervascular tumors (Figures 2-6 and 8), with areas of cystic degeneration and/or necrosis, whereas papillary (Figure 1) and chromophobe (Figure 9) types are usually more homogeneous and hypovascular[63-73]. Kim *et al*[63] studied the helical CT features of 110 RCCs, including tumor size, degree and patterns of enhancement, presence or absence of calcifications and tumor-spreading patterns. Clear cell RCCs showed stronger enhancement than the other histologic types, with a mean CT density of 106 ± 48 HU in the corticomedullary phase and 62 ± 25 HU in the excretory phase. When using 84 HU as the cutoff value in the corticomedullary phase and 44 HU in the excretory phase, the sensitivity and specificity for differentiating ccRCC from the other subtypes were 74% and 100%, 84% and 91%, respectively[63].

Jung *et al*[67] in a study of 149 small RCCs with MDCT, confirmed the presence of heterogeneous and strong contrast enhancement as more suggestive for the diagnosis of ccRCC, than the papillary and the chromophobe type. Young *et al*[68] recently reported their results on the histologic characterization of 277 RCCs with multiphasic MDCT, using up to four phases (unenhanced, corticomedullary, nephrographic, and excretory phase). Clear cell RCCs showed significantly greater enhancement in the corticomedullary phase (mean CT density: 125.0 HU) than do papillary RCCs (53.6 HU), and chromophobe RCCs (73.8 HU), reporting accuracies of 85% and 84%, respectively in their differentiation[68].

During the last 15 years, advances in the study of

Figure 9 The 31-year-old man with chromophobe renal cell carcinoma of the left kidney (stage T1b, grade Ⅱ). A: Axial plain image barely depicts upper pole left renal mass mainly isodense, with a slight bulging of the renal contour (arrow); B: Coronal reformation during the nephrographic phase clearly depicts left renal tumor (arrow). The neoplasm enhances moderately and homogeneously [computed tomography (CT) density: 70 HU, when compared to the CT density of 35 HU on unenhanced images]. A thin hyperdense rim surrounds renal malignancy, proved to correspond to fibrous pseudocapsule histologically.

ccRCC genetics have led to an improved understanding of the biological characteristics of this tumor, closely correlating with patient's prognosis and to the development of molecular targeted therapies[74-78]. More specifically, the gain of the long arm of chromosome 5 (5q), detected in a sub-set of ccRCCs, correlates with an improved 5-year survival rate and the loss of the short-arm of chromosome 9 (9p) correlates with a lower 5-year survival rate[74-78]. Common chromosomal anomalies in patients with ccRCC also include the loss of the short arm of chromosome 3, the loss of chromosome Y, the gain of the short arm of chromosome 5 and the gain of chromosome 7[73-77]. Sauk *et al*[78] in a retrospective study of 58 histologically proved and karyotyped ccRCCs reported a correlation between multiphasic MDCT features and cytogenetic characteristics of ccRCCs. In their study, ccRCCs with a deletion of chromosome 3p had fewer calcifications than those without this deletion. After contrast material administration, the authors reported greater enhancement for ccRCCs with loss of the Y chromosome than those without the anomaly during the corticomedullary phase (mean CT density: 130.0 HU *vs* 102.5 HU), also for ccRCCs with trisomy 5 than those with disomy 5 during the excretory phase (115.5 HU *vs* 83.4 HU), and for ccRCCs with disomy 7 than those with trisomy 7 during the corticomedullary phase (139.3 HU *vs* 105.8 HU)[78].

GRADING OF RCC

Advances in minimally invasive techniques and active surveillance protocols have allowed treatment of RCC without radical nephrectomy[1]. In these patients, core biopsy can be used to assess the pathologic characteristics of the tumor. However, core biopsy is not always adequate for the assessment of tumor nuclear grade (NG)[79,80]. NG is considered an independent predictor of cancer-specific survival[10-12]. RCCs of high NG are associated with early disease recurrence after therapy and with cancer-related mortality in patients with recurrent disease[10-12]. Therefore, a non-invasive method that could

help to predict the histologic characteristics, and more specifically NG in patients with RCC would be valuable. An inverse association between CT tumor enhancement and NG has been reported, with neoplasms of higher NG detected with lower enhancement on multiphasic contrast-enhanced CT examination[81-83]. Villalobos-Gollás *et al*[81] in a retrospective study of 48 RCCs, 44 of which were of clear cell variety evaluated the enhancement of the entire neoplasm on the image with most prominent areas of enhancement. The authors reported an association between higher NG and more advanced-stage disease with areas of lower enhancement of the tumor[81]. Zhu *et al*[80] examined tumor enhancement and relative enhancement values in the corticomedullary and nephrographic phases, by placing a region of interest as large as possible within the solid, more avidly enhancing parts of 255 ccRCCs. Age older than 58 years, irregular tumor margin, and corticomedullary phase relative enhancement value of 0.65 or less were identified as independent predictors of high tumor NG[80]. One possible explanation for the negative association between CT enhancement and NG is the presence of histologic necrosis within the tumor. Histologic necrosis has been reported to correlate with tumor aggressiveness, including higher NG and stage and larger size at diagnosis[80].

RCC SIZE

Tumor size is a significant part of the current TNM staging system[1,9]. It represents a highly important predictor of pathologic stage and survival in RCC[84,85]. Moreover, the selection of appropriate candidates for NSS, along with ablative therapies and active follow-up has been largely guided by tumor sizes evaluated by imaging modalities.

Although, some reports have shown a certain degree of discrepancy between the preoperative CT size of renal tumors and the pathologic size[86,87], discrepancies are minimal and clinically insignificant in most cases[88-90]. Chen *et al*[88] in a study of 169 renal tumors treated with NSS reported an overestimation of renal tumor

Figure 10 The 50-year-old man with clear cell-chromophobe renal cell carcinoma of right kidney (grade 3, pT1b). A: Coronal reformatted images in corticomedullary; B: Nephrographic phases depict hyperdense rim (arrowhead) surrounding the tumor; C: Histologic section (H and E, × 400) shows fibrous pseudocapsule (arrow) between tumor and adjacent normal renal parenchyma.

size by CT, as compared with the histopathology report. But the discrepancy was only 0.22 cm with little clinical significance, suggesting that CT is an accurate method to measure renal tumor size preoperatively[88]. Choi et al[89] in a study of 175 localized RCCs on a 16-row CT scanner, reported a good correlation between the CT and pathologic tumor sizes, although an overestimation of the size was observed for tumors less than 6 cm in diameter. Lee et al[90] in a retrospective study of 435 RCCs compared the radiographic tumor size, defined as the largest diameter measured on CT images with the pathologic size. Although, the authors found that CT size overestimated pathologic size, the observed differences were minimal, less than 1 mm, even for small-sized RCCs (4-5 cm in diameter, for which the discrepancies

were only about 2 mm), and therefore insignificant[90].

STAGING OF RCC

RCC confined to renal capsule
RCCs generally do not have a true histologic capsule, but are surrounded by a pseudocapsule[91]. The presence of a pseudocapsule surrounding RCC is considered as a histologic feature of early-stage disease[1,91]. These neoplasms are often of small size and of low grade[1,91]. Pseudocapsule formation is the result of tumor growth, producing compression, ischemia, and necrosis of the adjacent renal parenchyma, and resulting in deposition of fibrous tissue[91,92].

MRI has been reported as an accurate technique in the detection of renal pseudocapsule, when compared with CT, angiography and gray-scale sonography, with accuracies ranging from 74%-93%[93-96] Pseudocapsule appears as a hypointense rim between the neoplasm and the normal renal parenchyma on T2-weighted images[93-96]. Yamashita et al[94] in a study of 54 RCCs reported an accuracy of 74% in the detection of renal pseudocapsule with MRI and T2-weighted images. At contrast-enhanced CT, the psedocapsule was not visible in any tumors in this study, probably due to the similar contrast enhancement by both the pseudocapsule and the surrounding renal parenchyma[94]. Takahashi et al[95] assessed the diagnostic performance of multidetctor CT, selective angiography and MRI in the detection of renal pseudocapsule in 42 RCCs. A pseudocapsule was detected on 26% of neoplasms on CT, as a hypodense or hyperdense rim surrounding RCC, on 67% of neo-plasms on angiography, as a radiolucent rim and on 93% of tumors on T2-weighted sequences on MRI, as a low signal intensity rim[95]. Contrast-enhanced sonography improved the diagnostic performance of conventional ultrasound in the preoperative detection of renal pseudocapsule[97]. A sensitivity of 85.7% has been reported by Ascenti et al[97] with sonographic contrast agents, detecting pseudocapsule, as a contrast-enhancing rim, surrounding the tumor, usually with late enhancement.

Multiphase MDCT improved the diagnostic per-formance of CT in the detection of this finding[98]. A retrospective study of 29 RCCs reported an accuracy of 83% in the detection of renal pseudocapsule with MDCT. In this study a four-phase (unenhanced, arterial, portal and nephrographic-excretory phase) CT protocol and multiplanar reformations in the transverse, coronal and sagittal planes of each post-contrast phase were used for CT data interpretation. Portal and nephrographic phase, with coronal and sagittal reformations proved more accurate in the detection of this finding. Renal pseudocapsule was mainly detected as a hyperdense rim surrounding RCC, seen on both phases (Figures 2A, 9B and 10) and this was due to the presence of fibrous tissue. In four cases, a hypodense renal pseudocapsule was revealed (Figure 11) detected only on portal phase

Figure 11 The 44-year-old woman with clear cell renal cell carcinoma of left kidney (grade 2, pT1a). Computed tomography image demonstrates hypodense rim (arrowhead) around neoplasm detected only on coronal reformations during portal phase. The presence of pseudocapsule was confirmed on histology.

reformations[98].

Spread to perinephric tissues

The TNM classification system characterizes advanced RCC within Gerota's fascia as T3. T3a stage RCCs are characterized by tumor grossly invading the renal vein or its segmental branches, or invading perinephric (PN) fat and/or renal sinus (RS) fat[1]. RCCs with PN fat invasion have to penetrate the renal capsule, and tumors with RS fat invasion directly invade the RS fat, due to lack of any capsule at this area. The presence of either PN fat invasion or RS fat invasion, and invasion of both renal fat compartments were significantly associated with synchronous nodal or distant metastases, higher tumor grade and greater tumor dimensions, when compared to patients with no PN fat invasion[99]. Siddiqui *et al*[99] in a retrospective study of 163 pT3a RCCs concluded that PN and RS fat infiltration was associated with death from RCC independent of tumor size. Infiltration of the perinephric fat is also a crucial point when planning NSS. Radical nephrectomy is mandatory in these patients[1].

Perirenal or perinephric space is a cone-shaped retroperitoneal compartment, which is bounded by the anterior (Gerota's fascia) and posterior (Zuckerkandl's facsia) layers of the renal fascia and contains the kidney, adrenal gland, proximal ureter, a prominent amount of fat, a rich network of perirenal vessels and lymphatics, and small-sized lymph nodes[100,101].

The renal fascia measures 1-3 mm in thickness, and the posterior layer is thicker and more often visualized than the anterior layer[100,101]. Thickening of the renal fascia is a sensitive but nonspecific sign, indicating either neoplastic or non-neoplastic adjacent diseases[100,101]. Perinephric space is divided into multiple compartments by thin fibrous lamellae and bridging septa[102]. Kunin[102] described three groups of septa. Group Ⅰ septa arise from the renal capsule and extend to the renal fascia. Group Ⅱ septa are attached to the renal capsule, paralleling more or less the renal surface. Group Ⅲ represents the commonest type, connecting the anterior and posterior leaves of the perinephric space[102]. Thickening of the bridging septa (perinephric stranding) is not a reliable or specific sign in diagnosing neoplastic infiltration of the PN fat tissue[100,101]. A variety of neoplastic and nonneoplastic processes, may involve the perirenal space, including RCC, inflammation, edema, vascular engorgement, hematoma, or fat necrosis[100,101]. Perinephric stranding is also reported in about half of RCCs confined within the kidney.

Detection of PN fat invasion in RCC and differentiation between T1/T2 and T3a stages was the commonest staging error with spiral CT[5,33]. CT criteria used to diagnose neoplastic invasion of PN fat include the following: thickening of the renal fascia, thickening of the bridging septa (perinephric stranding), presence of fluid, presence of peritumoral vessels, defined as asymmetrically enlarged, often irregular vessels within Gerota's fascia, tumor margins and presence of neoplastic nodules within the PN fat, enhancing after contrast material administration[33,103-106]. Multiphase MDCT with multiplanar reformations improved the diagnostic performance of CT in detecting PN fat infiltration[33,103-106]. Catalano *et al*[33] by using three-phase MDCT protocol with thin slices reported an overall accuracy of 95% in diagnosing PN fat invasion, using the presence of hyperdense streaks and nodules surrounding RCC as CT signs to suggest neoplastic infiltration. Kim *et al*[105,106] reported high accuracies for MDCT in detecting PN fat invasion, using tumor size, irregular tumor margins and nodular appearance of the PN fat, as predictors for PN fat invasion. In a retrospective study of 48 RCCs on a 16-row CT scanner, the most significant predictors in diagnosing PN fat invasion were the presence of contrast-enhancing nodules in the PN fat and tumoral margins, with an overall accuracy of 85.4%, for both CT criteria (Figures 3B and 5C)[103].

The renal sinus is a central compartment formed by the extension of the PN space into the medial surface of renal parenchyma. The fibrous capsule terminates at the RS region, resulting in the absence of any barrier preventing the extension of neoplastic cells into the rich network of lymphatics vessels and veins within the RS[107]. RS fat invasion is associated with aggressive tumors at increased risk for dissemination. Thompson *et al*[108] showed that ccRCCs invading the RS fat are more aggressive that tumors with PN fat infiltration only. These neoplasms were more likely to have high NG, regional lymph node metastases and sarcomatoid differentiation. CT criteria used to diagnose invasion of RS fat include the following: extension to the renal sinus, proximity to the pelvicaliceal system, and invasion of the pelvicaliceal system[103]. Among them, renal collecting system invasion was proved to be the single most significant predictor of RS fat invasion (Figure 5D)[103]. None of the other two CT signs proved reliable in the diagnosis of RS fat infiltration. Some RCCs may distort the RS complex and protrude, without signs of invasion. The proximity of a tumor to a neighboring structure, as

Figure 12 The 64-year-old man with clear cell renal cell carcinoma of the right kidney, invading the renal vein and the inferior vena cava (stage T3b, grade 3). A: Coronal multiplanar reformations during the corticomedullary phase depicts large, inhomegeneously enhancing right renal tumor (arrow); B: Coronal 3D-display with maximum intensity projection technique during the same phase shows neoplastic thrombus invading left renal vein and the inferior vena cava (arrowheads). Coronal reformations clearly show venous invasion extending below the level of the diaphragm. Perinephric stranding and abnormal vessels are detected in the ipsilateral perinephric space, although pathology was negative for perinephric fat invasion.

the pelvicaliceal system, does not always correspond to neoplastic infiltration on histopathology[103].

Venous extension

Extension of RCC into the renal vein alone (stage T3a) occurs in approximately 23% of patients[4]. Tumor involvement of the inferior vena cava (T3b, T3c) is seen in approximately 4%-10% of patients and is more common in right-sided tumors[4]. A venous tumour thrombus (VTT) into the inferior vena cava in patients with RCC is a significant adverse prognostic factor[1]. Excision of the VTT is recommended in patients with non-metastatic RCC[1]. Accurate preoperative evaluation for the presence and extent of the VTT in the renal vein and/or the inferior vena cava is important for planning the appropriate surgical approach for thrombectomy, and minimizing the risk of intraoperative tumoral embolism[4,28-33,109-112]. The level of involvement of the inferior vena cava, whether infrahepatic, retrohepatic or supradiaphragmatic dictates the mode of surgical approach[113].

MDCT has been reported as highly accurate in the diagnosis of spread of RCC into the renal vein, with a reported negative predictive value of 97% and a positive predictive value of 92%[4,28-33,109-112]. MDCT is also effective in delineating the superior extent of inferior vena cava thrombus, with staging results similar to that of MRI[4,28-33,109-112]. Venous extension is optimally detected during the corticomedullary phase, when contrast enhancement of the venous system is maximal. The use of combination of axial images and multiplanar reconstructions is necessary for the assessment of the extension of VTT. The most specific sign of venous invasion is the presence of a low-attenuation filling defect within the vein. The CT characteristics of the thrombus help differentiate neoplastic from bland thrombus. Direct continuity of the thrombus with the primary malignancy suggests metastatic invasion. Heterogeneous enhancement of the thrombus, with a pattern similar to that of RCC also indicates tumoral thrombus (Figures

1B, 1C, 5B and 12)[4,28-33,109-112]. An abrupt change in the caliber of the vein and/or the presence of a clot within collateral veins are considered as ancillary findings suggesting neoplastic involvement. Enlargement of the renal vein alone is not a reliable sign, since it may be due to increased blood flow within a hypervascular RCC or it may represent a normal variant[4,28-33,109-112].

Invasion of the inferior vena cava wall (T3c) is considered an adverse prognostic sign, with a 5-year survival rate of 25% and 69% for patients with tumor invading the inferior vena cava wall and those with free-floating neoplastic thrombus into the inferior vena cava, respectively[45]. Infiltration of the inferior vena cava wall will also complicate surgical resection, because prosthetic reconstruction is usually needed in these patients[45,114]. Focal enhancement of the vena cava wall, or infiltration of adjacent soft tissues, indicates vena cava wall invasion on CT examination[45].

Local organ invasion (beyond the Gerota's fascia, including contiguous extension into the ipsilateral adrenal gland)

Assessment of the adrenal gland is important in patients with RCC for surgical planning. Multivariate analysis in a prospective study comparing the outcomes of radical or partial nephrectomy with, or without, ipsilateral adrenalectomy showed that upper pole tumor location was not predictive of adrenal involvement, but tumour size was predictive[115]. The current trend is to spare the ipsilateral adrenal gland, because ipsilateral adrenalectomy does not provide a survival advantage[1,115]. Adrenalectomy is justified in cases suspicious for metastatic spread, based on radiographic and/or intra-operative findings[1].

MDCT with multiplanar and 3D-reconstructions provide satisfactory results in assessing possible invasion of the adrenal gland[4,8-33,45]. Visualization of a normal adrenal gland at CT has been reported to be associated with a 100% negative predictive value for tumoral invasion, at pathologic analysis. CT signs that strongly suggest

Figure 13 The 70-year-old man with advanced-stage papillary renal cell carcinoma of the left kidney. Coronal multiplanar reformations during the nephrographic phase show large, mainly cystic left renal mass, with solid contrast-enhancing components (arrowheads). Enlarged retroperitoneal LNs, inhomogeneously enhancing (arrow, A) are detected, compatible with metastatic lymphadenopathy. Liver (arrowhead, B) and right adrenal (long arrow, B) metastases are also seen. All metastatic deposits have a similar pattern of enhancement.

invasion of the adrenal gland include the following: adrenal enlargement, displacement, or nonvisualization; adrenalectomy should be performed in these cases[4,28-33,45].

Direct extension of RCC outside Gerota's fascia and into neighboring organs (stage T4) is not always straightforward to diagnose, unless there is a definite focal change in CT density within the affected organ (Figures 3C and 8). Loss of fat tissue planes and irregular margins between RCC and adjacent organs raise the possibility of neoplastic invasion, although this is not always confirmed on histopathology[4,28-33,45]. Multiplanar and 3D-reconstructions help in depicting the relationship of RCC to the adjacent organs in multiple planes and orientations, therefore improving the diagnostic performance of MDCT[4,28-33,45].

Regional lymph node metastases
The presence of regional lymph node (LN) metastases in RCC implies a poor prognosis, with reported 5-year survival rates of 5%-30%[4]. The role of lymph node dissection in RCC remains controversial[4,116]. In patients with localized RCC, without clinical evidence of LN metastases, lymph node dissection is not recommended[1]. In patients with localized disease and clinically enlarged LNs, the survival benefit of LN dissection is unclear. In these cases, LN dissection is suggested mainly for staging purposes or local control[1]. Clinical assessment of LNs status is based on enlargement of LNs on CT and/or MRI and on intraoperative assessment by direct palpation. However, in patients with clinically enlarged LNs, only less than 20% of clinically positive LNs are confirmed to be metastatic at histologic examination[1].

The main CT criterion to diagnose metastatic LN involvement is the size[4,28-33,45]. Retroperitoneal LNs with a short-axis diameter larger than 1 cm are suspicious for neoplastic invasion (Figure 13). A cutoff value of 1 cm as the upper limit for normal LNs has significant limitations. One is the inability to recognize possible micro-metastases, resulting in false-negative findings in approximately 10% of cases. Furthermore, false-positive findings vary between 3%-43%, mostly due

to LN enlargement caused by reactive hyperplasia. The enhancement pattern of the node may also help differentiate reactive from malignant adenopathy; metastatic LNs usually present with heterogeneous enhancement. The presence of a hypodense center after contrast material administration, proved to correspond to necrosis on pathology, is considered a highly specific finding, with a positive predictive value of 100% in diagnosing metastatic lymphadenopathy. LNs enhancement with a pattern similar to that of the primary tumor also signifies metastatic disease (Figure 13).

Distant metastases
Metastatic disease occurs in a significant percentage of patients with RCC. At presentation, 25%-30% of RCCs have distant metastases[1]. A median survival of 6-9 mo has been reported for metastases left untreated and a 2-year survival rate of 10%-20% after treatment. The sites of distant metastases from RCC, in order of decreasing frequency are: lungs (50%-60%), bones (30%-40%), liver (30%-40%), and adrenal gland, contralateral kidney, retroperitoneum, and brain (5% each)[117]. Practically any organ may be affected.

Imaging has an important role in assessing the extent of metastatic disease. CT is considered the examination of choice in the detection of intraabdominal metastases (Figures 3, 13 and 14). Like the primary RCC, metastatic lesions are often hypervascular. The optimal phase for their detection is the corticomedullary phase, because they may be obscured on late-phase images.

CONCLUSION
Multidetector multiphase CT with multiplanar and 3D-displays remains the primary imaging modality for the detection of RCC, with high staging accuracies. CT features may prove useful in differentiating RCC from benign renal tumors. CT examination may help in the preoperative characterization of the histologic subtype of RCC. Tumor enhancement patterns of ccRCC

Figure 14 The 81-year-old woman with advanced-stage clear cell renal cell carcinoma of the left kidney. A: Transverse multiplanar reformation during the nephrographic phase shows large, inhomogeneously enhancing left renal malignancy (arrow), invading the ipsilateral renal vein (arrowhead); B: Contrast-enhanced computed tomography image of the thorax demonstrates enlarged mediastinal lymph nodes (arrow), with heterogeneous enhancement, suggestive for metastatic invasion.

are associated with Fuhrman grade and cytogenetic characteristics.

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EDITORIAL

Use of dentomaxillofacial cone beam computed tomography in dentistry

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Abstract

Cone-beam computed tomography (CBCT) was developed and introduced specifically for dento-maxillofacial imaging. CBCT possesses a number of advantages over medical CT in clinical practice, such as lower effective radiation doses, lower costs, fewer space requirements, easier image acquisition, and interactive display modes such as mutiplanar reconstruction that are applicable to maxillofacial imaging. However, the disadvantages of CBCT include higher doses than two-dimensional imaging; the inability to accurately represent the internal structure of soft tissues and soft-tissue lesions; a limited correlation with Hounsfield Units for standardized quantification of bone density; and the presence of various types of image artifacts, mainly those produced by metal restorations. CBCT is now commonly used for a variety of purposes in oral implantology, dento-maxillofacial surgery, image-guided surgical procedures, endodontics, periodontics and orthodontics. CBCT applications provide obvious benefits in the assessment of dentomaxillofacial region, however; it should be used only in correct indications considering the necessity and the potential hazards of the examination.

Core tip: Cone-beam computed tomography (CBCT) is now commonly used for a variety of purposes in oral implantology, dento-maxillofacial surgery, image-guided surgical procedures, endodontics, periodontics and orthodontics. CBCT applications provide obvious benefits in the assessment of dentomaxillofacial region, however; it should be used only in correct indications considering the necessity and the potential hazards of the examination.

CONE BEAM COMPUTED TOMOGRAPHY

Cone-beam computed tomography (CBCT) was developed and introduced specifically for dento-maxillofacial imaging[1]. A practical cone-beam algorithm for tomographic reconstruction of 2-D projection data was first illustrated by Feldkamp in 1984, who, used a back-projection formula to directly reconstruct a 3-D density function from a set of two-dimensional projections. CBCT units dedicated to dento-maxillofacial radiology could not be marketed for another 15 years because economic X-ray tubes, high-quality detector systems and sufficiently powerful personal computers were unavailable. Eventually, in 1999, the first dento-maxillofacial CBCT unit, the NewTom DVT 9000, designed by Attilio Tacconi and Piero Mozzo and produced by QR, Inc. of Verona, Italy, was introduced in Europe[2,3]. Today, new technological specifications and settings include multiple field of views (FOVs) and voxels that can better address a variety of specific tasks. There are also several hybrid machines offering CBCT imaging along with panoramic and cephalometric radiography. CBCT possesses a number of advantages over medical CT in clinical practice, such as lower effective radiation doses, lower costs, fewer space requirements, easier image acquisition, and interactive display modes such as mutiplanar reconstruction that are applicable to maxillofacial imaging. However, the disadvantages of CBCT include higher doses than two-dimensional imaging; the inability to accurately represent the internal structure of soft tissues and soft-tissue lesions; a limited correlation with Hounsfield Units for standardized quantification of bone density; and the presence of various types of image artifacts, mainly those produced by metal restorations[4-6].

CBCT is now commonly used for a variety of purposes in oral implantology, dento-maxillofacial surgery, image-guided surgical procedures, endodontics, periodontics and orthodontics. Whereas early CBCT devices were dedicated to implantology and dental imaging, today, applications extend to the face and skull base as a whole. Depending on the FOV used, CBCT images may show part or all of the nasal cavity, paranasal sinuses, airway, cervical vertebrae and temporal bone. In fact, specific ear, nose and throat imaging programs have been increasingly included in CBCT systems, suggesting that CBCT may at some point entirely replace medical CT imaging in certain otolaryngology-related applications[3]. CBCT has also been found to provide reliable and accurate 3D analysis of the upper airway that can be of help in assessing the presence and severity of obstructive sleep apnea[7]. Imaging of the temporal bone represents another promising area for CBCT, whose high-resolution and nearly artifact-free multi-planar reconstruction images make it possible to precisely assess the intra-cochlear position of the electrode, including visualization of each individual contact[8].

Concerns over liability issues related to CBCT remain unresolved. CBCT machines are increasingly being marketed specifically to orthodontists and implantologists or dentists who place implants in private practices. Unlike other advanced medical imaging systems, CBCT scanners are generally owned and operated by non-radiologists who lack the training necessary to interpret CBCT images. However, clinicians who order CBCT scans are responsible for interpreting the entire image volume, given the possibility that incidental findings - the likelihood of which increase when a larger head volume is included in the scan - may have significant health consequences for the patient[6]. There is no informed consent process or signature waiver that would allow the clinician to interpret only a specific area of an image volume. As a result, the clinician may be considered liable for a missed diagnosis, even one that falls outside the area of his/her expertise. In case of any questions regarding image data interpretation, referral to a specialist in oral and maxillofacial or medical radiology is recommended[6,9].

CBCT applications provide obvious benefits in the assessment of dentomaxillofacial region, however; it should be used only in correct indications considering the necessity and the potential hazards of the examination. Comparative radiation dosages should be weighed against diagnostic benefits in selecting the appropriate imaging modality for specific purposes. Future improvements in CBCT imaging can be expected to result in novel systems with better diagnostic abilities and lower effective doses[10].

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EDITORIAL

Contrast-enhanced ultrasound imaging of the vasa vasorum of carotid artery plaque

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Abstract

The vasa vasorum of carotid artery plaque is a novel marker of accurately evaluating the vulnerability of carotid artery plaque, which was associated with symptomatic cerebrovascular and cardiovascular disease. The presence of ultrasound contrast agents in carotid artery plaque represents the presence of the vasa vasorum in carotid artery plaque because the ultrasound contrast agents are strict intravascular tracers. Therefore, contrast-enhanced ultrasound (CEUS) is a novel and safe imaging modality for evaluating the vasa vasorum in carotid artery plaque. However, there are some issues that needs to be assessed to embody fully the clinical utility of the vasa vasorum in carotid artery plaque with CEUS.

Core tip: Stroke is a major cause of morbidity and mortality all over the world. At-risk patients is so-called vulnerable patients because they posses a higher likelihood of developing symptomatic stroke compared with those low-risk patients. Vulnerable patients usually have carotid artery vulnerable plaques and vulnerable plaques posses a higher likelihood of rupture to lead to acute stroke. The vasa vasorum of carotid artery plaque has been confirmed as same as vulnerable plaques and contrast-enhanced ultrasonography could detect the vasa vasorum of carotid artery plaque.

Song ZZ, Zhang YM. Contrast-enhanced ultrasound imaging of the vasa vasorum of carotid artery plaque. *World J Radiol* 2015; 7(6): 131-133 Available from: URL: http://www.wjgnet.com/1949-8470/full/v7/i6/131.htm DOI: http://dx.doi.org/10.4329/wjr.v7.i6.131

INTRODUCTION

The plaques with a thin fibrous cap covering a large lipid necrotic core, and active inflammation is so-called vulnerable atherosclerotic plaque, which that make the plaque at increased risk of rupture[1]. The vasa
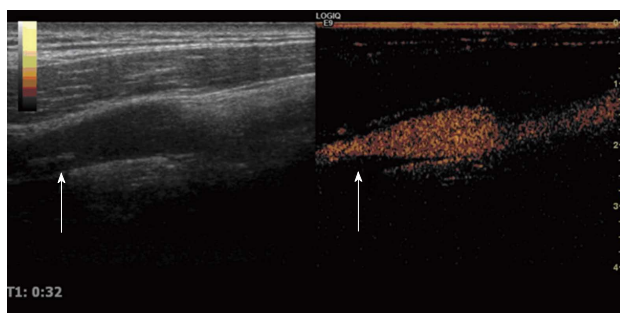
Figure 1 Presence of the vasa vasorum in carotid artery plaque. There are mild ultrasound contrast agents in carotid artery plaque (arrow).
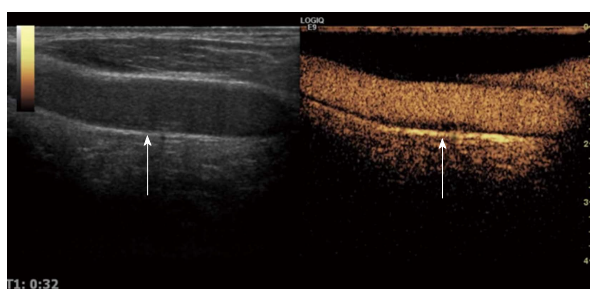

Figure 2 Presence of the vasa vasorum in carotid artery plaque. There are abundant ultrasound contrast agents in carotid artery plaque (arrow).

vasorum of carotid artery plaque is a novel marker of accurately evaluating the vulnerability of carotid artery plaque[1,2]. The presence of vasa vasorum in carotid artery plaque has been associated with symptomatic cerebrovascular and cardiovascular disease[3,4] because the vasa vasorum in carotid artery plaque is increased risk for rupture, causing intraplaque hemorrhage and subsequent rapid progression to symptomatic disease.

Recently, contrast-enhanced ultrasound (CEUS) has been introduced for identifying the presence of the vasa vasorum in carotid artery plaque[5-9], therefore, CEUS is capable of assessing atherosclerotic carotid lesions at risk for rupture[5,10]. The currently approved and used agents are SonoVue (Bracco SpA, Milan, Italy) in china. Ultrasound contrast agents have been administrated in millions of patients and are safe and side effects are extremely rare[11]. The presence of ultrasound contrast agents in carotid artery plaque represents the presence of the vasa vasorum in carotid artery plaque (Figures 1 and 2) because the ultrasound contrast agents (SonoVue) are strict intravascular tracers, and the appearance of contrast enhancement of CEUS was shown to correlate with the presence and degree of the vasa vasorum in carotid artery plaque which were assessed by histology[12,13].

PERFORMANCE OF CEUS

After implemented in the routine carotid ultrasound scan acquisition protocol, CEUS of carotid artery plaque can be relatively straightforward[8,9]. Firstly, a venous access catheter is placed into median vein of elbow. Secondly, the contrast presets of the ultrasound system are selected, which are available in nearly all currently used vascular ultrasound systems. Carotid CEUS imaging usually uses a linear array transducer that transmits frequencies are between 5 and 10 MHz and a low-level mechanical index condition is used to avoid destruction of the microbubbles[8,9]. Thirdly, high quality CEUS dynamical images of the continuous appearance of carotid artery plaque can be obtained after ultrasound contrast agent followed by a 5 mL saline flush are injected into median vein of elbow according to venous access catheter[8,9]. Usually, the optimal time window for the performance of CEUS after administration of the contrast agent is approximately in 2 min[8,9]. Lastly, the ultrasound contrast signal intensity becomes weaker because the ultrasound contrast agent is eliminated after a few minutes, and administration of the ultrasound contrast agent can be repeated[8,9].

FUTURE PERSPECTIVES

Criterion of assessment

There are too many criterions about assessment of the vasa vasorum in carotid artery plaque with CEUS at the present[4-9,12,13], which includes quantitative criterion, semi-quantitative criterion and qualltative criterion[4-9], therefore, the criterion of assessment of the vasa vasorum in carotid artery plaque with CEUS is inconsistent among all kinds of clinical studies[4-9,12,13]. Thus, the clinical value of the vasa vasorum in carotid artery plaque with CEUS yet remain sure accurately, therefore, the criterion about assessment of the vasa vasorum in carotid artery plaque with CEUS should be assessed in the future studies.

Dosage of ultrasound contrast agent

The dosage of ultrasound contrast agent was different among some studies[4-9]. To our experience[8,9], 1.2 mL ultrasound contrast agent followed by a 5 mL saline flush acquire high quality CEUS dynamical images of the continuous appearance of carotid artery plaque, although some studies and authors propose 2.4 mL or 2.0 mL ultrasound contrast agent followed by a 5 mL saline flush[4-6,12,13]. However, the different dosage of ultrasound contrast agent could cause the results according to quantitative criterion, semi-quantitative criterion and qualltative criterion significantly discrepancy, therefore, the dosage of ultrasound contrast agent should be unified according to the quality of CEUS dynamical images and cost-effectiveness.

Consistency and repetition

The clinical studies[4-9,12,13] about the vasa vasorum in carotid artery plaque with CEUS are exciting because the authors think the method could provide early detection and classification of atherosclerotic disease, however, consistency and repetition of the method is poorly established[4-9,12,13]. The lowness of consistency and repetition could cause the method not extensive

use, therefore, consistency and repetition of the method needs to be assessed in prospective studies.

Accuracy of diagnosis

It is well known that the vasa vasorum in carotid artery plaque with CEUS were well correlated with histologic specimens obtained after endarterectomy[5-7], however, the diagnosis accuracy of the histologic degree of the vasa vasorum in carotid artery plaque using CEUS remain unclear. Therefore, this issue should be assessed in the future perspective study.

Perspective study

Most of the studies about the vasa vasorum in carotid artery plaque with CEUS are retrospective studies[7-9], therefore, too many issues about the clinical utility of the vasa vasorum in carotid artery plaque with CEUS remain unclear. In addition, most of studies about the vasa vasorum in carotid artery plaque with CEUS are small-scale, which causes the results of these studies unimpressive. Therefore, the large-scale perspective studies should be performed to assess the clinical utility of the vasa vasorum in carotid artery plaque with CEUS.

CONCLUSION

CEUS is a novel and safe imaging modality for evaluating the vasa vasorum in carotid artery plaque, which could detect the vulnerable plaque at risk for rupture. However, there are some issues that needs to be assessed to embody fully the clinical utility of the vasa vasorum in carotid artery plaque with CEUS and the perspective studies needs to be performed to resolve the above-mentioned issues and assess the clinical utility of the vasa vasorum in carotid artery plaque with CEUS.

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MINIREVIEWS

Risk management in radiology departments

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Abstract

Medical imaging and interventional radiology sustained prompt changes in the last few years, mainly as a result of technology breakthroughs, rise in workload, deficit in workforce and globalization. Risk is considered to be the chance or possibility of incurring loss or of a negative event happening that may cause injury to patients or medical practitioners. There are various causes of risks leading to harm and injury in radiology departments, and it is one of the objectives of this paper to scrutinize some of the causes. This will drive to consideration of some of the approaches that are used in managing risks in radiology. This paper aims at investigating risk management in radiology, and this will be achieved through a thorough assessment of the risk control measures that are used in the radiology department. It has been observed that the major focus of risk management in such medical setting is to reduce and eliminate harm and injury to patients through integration of various medical precautions. The field of Radiology is rapidly evolving due to technology advances and the globalization of healthcare. This ongoing development will have a great impact on the level of quality of care and service delivery. Thus, risk management in radiology is essential in protecting the patients, radiologists, and the medical organization in terms of capital and widening of the reputation of the medical organization with the patients.

Key words: Risk management; Radiology; Patient safety

Core tip: This paper serves as a review of risk management in radiology. It investigates the potential sources of risk within radiology departments and proposes measures that may potentially mitigate these risks. A major focus of risk management is to reduce harm and injury to patients and personnel and it aims to improve the outcomes from radiology departments. Risk management in radiology is essential in protecting the patients, radiologists, and the medical organization.

Craciun H, Mankad K, Lynch J. Risk management in radiology

INTRODUCTION

Medical imaging and interventional radiology have sustained dramatic changes in the last few years, mainly as a result of technological breakthroughs, the rise in workload, a deficit in the workforce and globalisation. Consequently there is an expanding concern about standards of care, maintaining patient safety and the management of risk in radiology.

People understand the concepts of risk and risk management in a medical setting in different ways. Risk is considered to be the possibility of incurring loss or of a negative event occurring that may cause injury to patients or medical practitioners[1]. One cannot predict all risks. That is to say, injury to patients may occur even in the best hospitals where patients receive high-quality services and treatments. Then risk management refers to the various approaches that medical practitioners and professionals integrate to reduce risk[2]. This is a proactive concept that involves practices such as identification of risk, quantification and evaluation of risk and consideration of measures that can be used to eliminate or control risk in a medical setting. All those involved in providing healthcare services participate in risk management. This includes management of the medical centres obligated to provide adequate facilities, staff, resources, financial support and equipment, thus helping professionals and nursing practitioners reduce the odds of harm's occurring[3].

This paper aims at investigating risk management in radiology through a thorough assessment of the risk control measures that are used in the radiology department[4]. The major focus of risk management in such medical settings is to reduce and eliminate harm and injury to patients through the incorporation of various medical precautions[5]. As depicted in Figure 1 risks leading to harm and injury in radiology departments stem from various causes. One objective of this paper is to scrutinise some of these. This will expand into the consideration of some of the approaches healthcare practitioners implement to manage risk in radiology.

RISK MANAGEMENT

Safeguarding patients and personnel

The rapid expansion of services, the globalization of healthcare and the imbalance between workload and workforce are a few of the factors that may threaten the standards of health services as well as patient safety[6]. There is a rising demand for radiologists and for 24/7 services. Therefore, international teleradiology is leading the globalisation occurring in the field of radiology[7].

To meet the expectations of quality services, systems should be put in place to pave the way for higher standards of care. Quality systems are effective risk control measures, hence the importance of professional organisations to lead, establish, uphold and improve them[8]. Quality improvement measures range from quality maps, measurable metrics and performance indicators to audits and accreditation programmes. These collective efforts may decrease a department's risk and benefit patients[9].

Risk management in radiology is primarily developed and fostered to help safeguard patients, working personnel and the entire organisation. Protection of the organisation is largely grasped in terms of finance management and potential drawbacks linked to unreliable results that could damage its reputation[10].

Managers and clinicians in the radiology department should focus on improving the general quality of care medical staff deliver to patients. Radiology professionals subject themselves to risk every time they perform a procedure because some of the techniques and instruments they use in scanning and imaging are complex[11]. Thus, players in the healthcare setting must work carefully and diligently to ensure that they minimise health risk to patients and to themselves. In practice, inherent hazards to safety and quality manifest in relation to personnel availability, workload and financial predicaments. They consist of insubstantial funding for new equipment in the workplace, difficulty retaining professionals, the escalating complexity of the work, the increasing workload, difficulty recruiting due to a national shortage of medical staff and the lessening budget that is not keeping up with current of demands.

Radiology professionals must persuade administrators and managers that standards of care relate closely to performance metrics like workload, diagnostic precision and patient safety concerns[12]. Thus, managers must make sensible decisions about resource allocation and performance expectations to mirror this reality and curtail risks[10].

All health professionals must identify some of the issues that tend to cause harm to patients in advance and work on them before subjecting the patient to potentially faulty processes[13]. The concept of ALARP, or "as low as reasonably practicable", essentially refers to the assessment of risk, and the comparison of this risk with the amount of time, money and resources needed to address it. It is used throughout the healthcare system and is particularly important when it comes to radiology. When assessing whether a risk is ALARP, it is essential to compare the measures being proposed with those that would normally be used, also known as "good practice". Good practice is decided upon after detailed discussion with stakeholders. However, good practice is not always enough, and if an issue is particularly complicated, or if no good practice has yet been formulated for the issue, it is often necessary to revert back to the "first principle". In sum, ALARP is about calculating the amount of risk attached to measures, and assessing how difficult, in terms of resources, controlling this risk is. It offers those
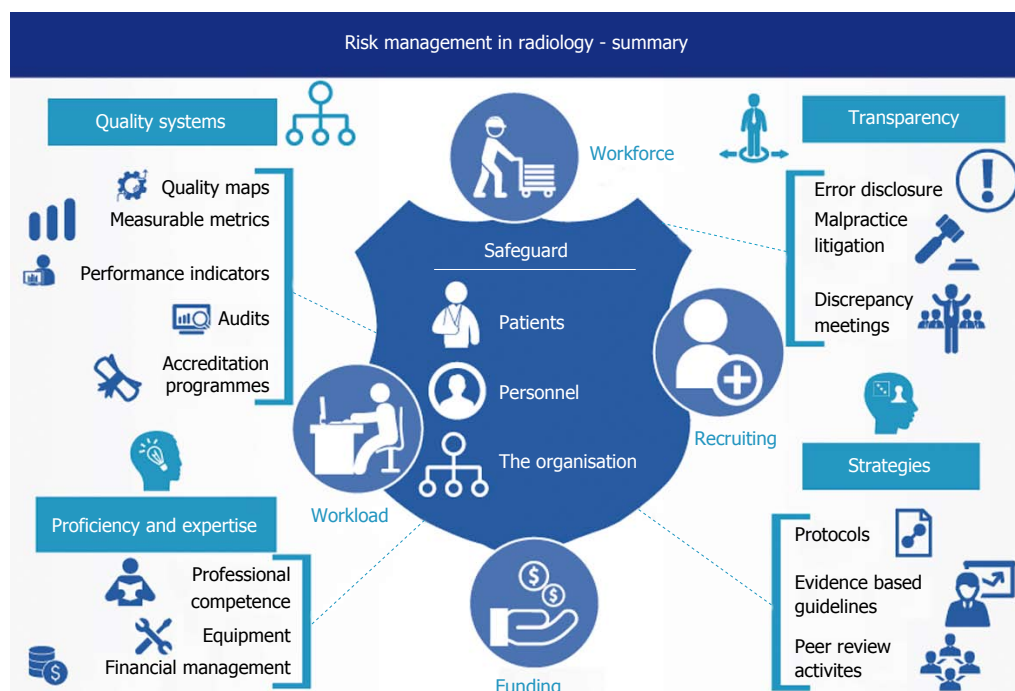
Figure 1 Summary of control measures in risk management in radiology.

who use it a great deal of flexibility, as it involves the setting of goals, thus allowing room to manoeuvre if necessary.

Risk management allows radiologists to focus on measures for reducing potential risk. This ensures that medical staff follow appropriate and relevant protocols and guidelines to reduce risk in radiology departments[14].

Error disclosure and malpractice litigation
Recent studies on malpractice suits[15] revealed that amongst the most frequent causes of legal claims against radiology professionals were: diagnostic errors followed by procedural complications, poor communication with the referring doctor and poor physician-patient rapport[16]. Risk management is a crucial instrument in preventing and limiting adverse events and errors in medical settings[17].

The most common medical errors encountered in malpractice suits are vascular injuries and complications after needle biopsies in interventional radiology[18], missed or delayed cancer diagnosis especially in imaging of the breast[19] and missing diagnosis in skeletal radiology[17]. A major objective in risk management is the reduction of litigation and the associated costs. The magnitude of these costs should suffice to argue that avoiding the problems that may cause lawsuits positively impacts the patients and radiologists[20].

The reduction of errors in a radiology department is attainable if all parties in the department are aware of and up to date with all the methods and protocols involved in risk reduction[21].

One can manage litigation risk in a radiology department through a number of approaches. Healthcare professionals should set up and follow high standards of care, employ prudence when using devices off label[22,23], improve communication skills with colleagues and patients[24] and obtain professional liability insurance.

Stakeholders, including radiologists, must possess competence and significant knowledge and skills in working with all the implements within the radiology department as a way of reducing the number of errors[25]. Every radiologist should be conscious of error sources, particularly those typically constituting origins of litigation[26]. Medical staff must unveil and emphasise error pitfalls to prevent the recurrence of inaccuracies[27].

In the future, various factors will shape radiological malpractice: the emergence of new imaging techniques, innovation in image processing, new protocols scientific societies publish and guidelines professional organisations delineate[28]. To minimise risk, medical staff should cultivate a safety culture in every radiology department and perceive feedback on a possible error as a learning experience[29]. The radiologists and other key players in the department need to understand that their practice and performance significantly contribute to the trust patients place in them[30]. Radiologists need to provide good standards of practice and care and show respect for a patient[31].

Disclosing radiological errors to patients stands out as the most demanding challenge a radiologist may encounter. With a misguided error disclosure approach, radiologists risk not meeting professional norms in addition to creating erratic and unsafe practice patterns[32].

Failure to acknowledge responsibility and achieve transparency around errors subverts patient safety. Despite this, risk management concerns about litigation have long precluded the endorsement of standards around error disclosure. More recently, risk managers

have emphasised that clear disclosure after radiological errors is crucial to risk management and can reduce exposure to liability[33].

Professional competence and equipment

Medical practitioners in the department must ensure that they keep their knowledge and skills updated. To achieve competencies and proficiency in their areas of expertise, radiologists must perform their duties within the limits of their understanding and competence[34]. This allows them to do what they understand best, thus reducing the probability of causing danger, harm or injury to patients[8]. The requirement is closely related to the recommendation that the radiologists need to maintain high trust and confidentiality with their clients through the establishment of a professional relationship[35]. Moreover, workers attain competence in a medical setting if they comprehend and appreciate the benefits of collaborating with other professionals in their field[36]. This implies that to reduce risk in radiology departments, doctors need to work as a team, combine their knowledge and skills and, more importantly, share their experience as a way of promoting excellence in their field[37].

Modern radiology is greatly reliant on the application of state-of-the-art diagnostic and therapeutic devices, but such state-of-the-art technology carries risk. To avoid the risk associated with the use of faulty devices in the radiology sector, quality assurance departments must be diligent in ensuring that all the equipment used is in good condition and of high quality[38].

Risk management relating to the use of therapeutic devices requires all professionals to possess sufficient knowledge, skills and technical ability to operate the devices, recognise when they break down and identify inaccurate results.

Through integration of appropriate skills and operational strategies in radiology, professionals can guarantee the highest accuracy. The attainment of excellent results and a foolproof reporting procedure highlights a department's competence, indicating the department's use of protocols and guidelines focused on reducing operational and decisional risk[39].

Discrepancy, errors and critical incidents

Integrated teamwork among radiologists would support risk reduction and prevent any issue that may cause harm or injury to patients through inadequate reporting, resulting in unreliable results[40]. Radiologists must justify their individual decisions and actions. To be able to manage risk in the radiology sector, practitioners need to learn from previous mistakes and, more importantly, scrutinise critical clinical situations and near misses. Physicians are prone to making errors, but integrating certain operational decisions and measures would reduce the rate of errors and near misses[41].

Risk management is founded on the idea that mistakes happen and processes and procedures sometimes go wrong. Therefore, holding regular meetings where medical staff can report and evaluate discrepancies,

errors and near misses is crucial[42]. Discrepancy meetings are invaluable in medical practice and offer the opportunity to assess current practice and highlight areas that might need improvement[11]. The Royal College of Radiologists recommends that all radiologists attend discrepancy meetings and morbidity and mortality meetings. Evidence of attendance may be required to support the revalidation process, so doctors should carry out personal reflections[43]. Inappropriate conduct, such as unethical handling of a patient's records and intentional carelessness, is a contributing factor to errors. However, medical staff can mitigate this factor through adherence to department and/or organisational procedures and protocols[39].

CONCLUSION

The field of radiology is rapidly evolving due to technological advances and the globalisation of healthcare. This ongoing development greatly affects the quality of care and service delivery. Doctors and professional organisations should display initiative and oversee and tackle challenging conditions in an effective manner to safeguard patient safety and standards of care. The quality of a radiological report relies on the various important steps outlined above. The essence of risk management is to survey all potential reasons for an inaccurate report in advance so that procedures can be put in place to prevent them. More importantly, the medical organisation offering radiology services needs to allow innovation and responsive measures that can improve radiology. Thus, risk management in radiology is essential in protecting the patients, radiologists and medical organisation (*i.e.*, protecting the organisation's capital and its reputation with patients).

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CASE REPORT

Endovascular retrieval of a prematurely deployed covered stent

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Abstract

Several techniques have been reported to address different endovascular device failures. We report the case of a premature deployment of a covered balloon mounted stent during endovascular repair of a post-traumatic carotid-cavernous fistula (CCF). A 50-year-old male suffered a fall resulting in loss of consciousness and multiple facial fractures. Five weeks later, he developed decreased left visual acuity, proptosis, chemosis, limited eye movements and cranial/orbit bruit. Cerebral angiography demonstrated a direct left CCF and endovascular repair with a 5.0 mm × 19 mm covered stent was planned. Once in the lacerum segment, increased resistance was encountered and the stent was withdrawn resulting in premature deployment. A 3 mm × 9 mm balloon was advanced over an exchange length microwire and through the stent lumen. Once distal to the stent, the balloon was inflated and slowly pulled back in contact with the stent. All devices were successfully withdrawn as a unit. The use of a balloon to retrieve a prematurely deployed balloon mounted stent is a potential rescue option if leaving the stent *in situ* carries risks.

Key words: Stent retrieval; Covered stent; Premature stent deployment

Core tip: Increasingly complex neurovascular lesions are now amenable to endovascular therapy due to the development of new devices and techniques. However, malfunction or failure of these devices remains a potential hurdle to a successful treatment. Consequently, a growing body of reports describing rescue and salvage techniques have emerged. In this report, we discuss the endovascular retrieval of a prematurely deployed covered stent during the treatment of a traumatic carotid-cavernous fistula.

INTRODUCTION

Increasingly complex neurovascular lesions are now amenable to endovascular therapy due to the development of new devices and techniques. However, malfunction or failure of these devices remains a potential hurdle to a successful treatment. More commonly, endovascular device malfunction has been reported in the setting of intracranial aneurysm coil embolization or stent placement. Consequently, a growing body of reports describing rescue and salvage techniques has emerged[1-6]. In this report, we discuss the endovascular retrieval of a prematurely deployed covered stent during an attempted treatment of a traumatic carotid-cavernous fistula (CCF).

Clinical presentation

A 50-year-old right-handed man was repairing an elevator when he sustained a 20-foot fall, resulting in loss of consciousness. He was taken to a local hospital where a left wrist, multiple rib and craniofacial fractures were discovered. All fractures were managed conservatively. By the end of his five-week hospital stay, he began to experience a roaring tinnitus that was only mainly audible at night, horizontal diplopia, decreased visual acuity, chemosis and proptosis of the left eye.

One week later, the patient was referred to our institution to address his worsening left ocular symptoms. On initial examination, we noted a cranial and orbital bruit, decreased left visual acuity (20/100), left afferent papillary defect, proptosis, chemosis and limited eye movements in all directions. The remainder of his neurological examination was unremarkable. Computerized tomography of the head demonstrated fractures of the left zygomatic arch, left lateral orbital wall, a prominent left superior ophthalmic vein, and a left parietal hypodensity consistent with a subacute ischemic infarct. A conventional diagnostic cerebral angiogram demonstrated a left CCF in the horizontal cavernous segment of the left intracranial cavernous angiomas (ICA) (barrow type A)[7] with angiographic steal from the intracranial circulation and flow reversal into the cavernous sinus tributary veins.

CASE REPORT

Intended treatment

Due to the symptoms of the patient and concerns for visual loss conservative management was not considered. Given the lack of established guidelines in the treatment of CCFs and our previous successful experience in the treatment of CCFs with a covered stent, it was decided to use a covered stent in the left cavernous ICA at the site of the fistula. In our experience previous cases of CCFs treated at our institution were mainly performed with coil embolization of the cavernous sinus but often requiring several procedures, recently we had a success with the use of a covered stent. Prior to the procedure, emergent internal review board consent was obtained for the off label use of a covered stent. Through a 7 French (Fr) introducer sheath (Cordis, Miami, FL) in the right femoral artery, a 7 Fr Brite Tip multipurpose catheter (Cordis, Miami, FL) was advanced into the distal cervical segment of the left ICA. We navigated a microcatheter (Excelsior SL-10, Boston Scientific, Natick, MA) into the proximal left middle cerebral artery and exchanged it over a microwire (Luge Wire, Boston Scientific, Natick, MA) for the covered stent delivery system. With the microwire positioned in the distal M2 division, we advanced intracranially a 5 mm × 19 mm covered stent (Graft-Master JoStent, Abbott Laboratories, Abbott Park, IL) over the microwire.

Once the stent delivery system was in the proximal vertical segment of the left cavernous ICA, we noted increased resistance and difficulty in advancing the system past the posterior genu of the cavernous segment. The guide catheter was pushed back proximally as the resistance increased, therefore we determined that the covered stent could not be delivered through our system and it had to be withdrawn. Upon withdrawal of the devices, we noted the stent was no mounted on the balloon. Fluoroscopy demonstrated that the stent had been prematurely deployed into the lacerum segment of the ICA (Figure 1) and the un-inflated balloon of the stent system was not abating the wall of the vessel.

Covered stent retrieval

Under roadmap guidance, a 3 mm × 9 mm Maverick balloon (Boston Scientific, Natick, MA) was advanced over a 0.014 microwire (Transcend, Boston Scientific, Natick, MA) through the lumen of the stent. The distal end of the microwire was positioned in the left A1. Once the balloon was distal to the stent, the balloon was inflated to a subnominal pressure and pulled back in contact with the distal end of the stent (Figure 2). The stent was dragged back over the wire to the distal end of the guide catheter. Ensuring the stent was trapped between the guide catheter and the balloon all the devices were withdrawn at once (Figure 3).

Clinical outcome

The patient in the same procedure underwent transvenous coil embolization of the cavernous sinus, however it was required to keep the patient intubated and be brought back the next day to achieve complete embolization of the fistula (coil length of 390 cm). At follow up a few weeks later, the proptosis, chemosis and bruit resolved along with improvement in the extraocular movements and visual acuity.
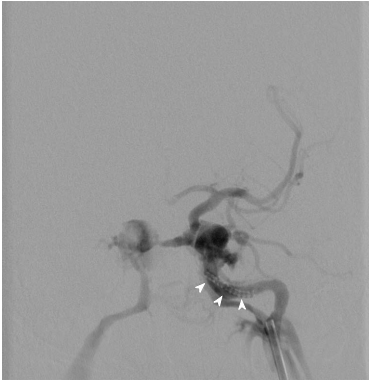
Figure 1 Anteroposterior view of left internal carotid injection (early arterial phase) showing the carotid cavernous fistula and prematurely deployed stent in the petrous segment (arrowheads).
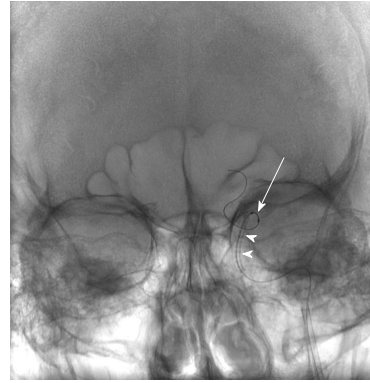

Figure 2 Anteriorposterior fluoroscopic view, that demonstrates the microwire in the left anterior cerebral artery and the balloon markers (arrow) distal to the stent (arrowheads) in preparation for the stent retrieval.
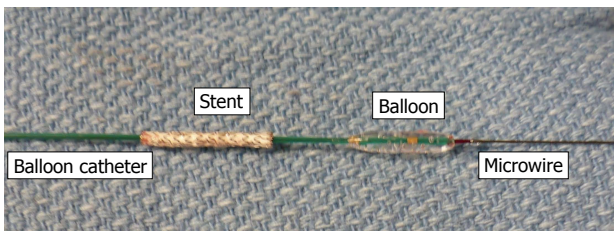

Figure 3 Balloon-catheter, stent, balloon and microwire following retrieval.

DISCUSSION

There is a growing body of literature focused on salvage techniques for neuroendovascular complications, and the operator must be prepared to manage intraprocedural complications including those related to device failure. Effective and successful rescue maneuvers unique to each device should be reported.

The successful use of covered stents in the treatment of CCF has been reported[8-12], but their poor navigability in the intracranial circulation is also well-described. Factors that contribute to a difficult stent delivery into the intracranial circulation include tortuous vascular anatomy, unstable positioning of the guide catheter, and poor stent navigability. The Graft-Master JoStent (Abbott Laboratories, Abbott Park, IL) is composed of a polytetrafluoroethylene sheet fixed between two stainless steel stents, mounted on a semi-compliant balloon that requires a ≥ 7 Fr guide catheter and ≤ 0.014 inch wire for device delivery. This design results in inherent stiffness and poor navigability of the device. Excessive application of force may not overcome the poor navigability and may lead to proximal herniation of the guide catheter or premature deployment of the stent. Our patient did not appear to have prominent tortuous vessels, consequently, we believed that we could advance the covered stent to the cavernous segment with minimal resistance. Although large series are lacking, failure to deploy a covered stent has been previously reported[13]. A better proximal support by having a telescoping system with the guide catheter supported by an additional long sheath may have helped

with navigation and prevented premature deployment of the stent. A shorter covered stent (12 mm) could have been easier to advance, however we were not convinced that its length would properly have covered the fistulous point.

The prematurely deployed stent was noted after the removal of the stent delivery microcatheter and its guide wire. In addition, this resulted in loss of access to the lumen of the stent and posed the challenging task to pass a wire back through the stent. Nevertheless, we were concerned that leaving a stent not abating the wall of the vessel could increase the risk of thromboembolic complications with or without stent migration, therefore we chose to attempt the stent retrieval.

The retrieval of misplaced or malfunctioning devices in neuroendovascular procedures have been performed using snares[1], the Alligator retrieval device (Chestnut Medical, Menlo Park, CA)[3] or the Merci retriever (Concentric, Mountain View, CA)[6]. In coronary procedures however, the reported incidence of coronary stent loss or premature stent-balloon separation resulting in embolism is reported to be in the range of 0.27%-3.4%[14,15]. The retrieval in this setting often involves the use of a small distal balloon, loop snare, two wires around the stent or biopsy forceps[14-19]. This migration or premature deployment in neuroendovascular procedures is a relatively uncommon complication since most commercially available intracranial stents are self-expandable[20,21].

The technique of passing a balloon within the lumen of the stent is a well described technique in interventional cardiology for the retrieval of migrated stents[14-16,22,23]. The balloon is used to drag the stent proximally to the tip of the guide catheter. Once all are in contact (balloon-stent-guide catheter), the entire system is removed in one unit. Although in this case the rescue was successful, we acknowledge that the rescue might have carried additional challenges such as failure of retrieval and arterial dissection.

The retrieval of an early deployed balloon mounted stent is possible. The use of a balloon to drag the stent back into the guide catheter is a potential rescue option

if leaving the stent *in situ* carries risks.

COMMENTS

Case characteristics
Blurred left eye vision, double vision and tinnitus developed after a fall.

Clinical diagnosis
Chemosis, proptosis of the left eye, an orbital bruit was noted.

Differential diagnosis
An arteriovenous fistula was suspected and demonstrated with neuroimaging.

Imaging diagnosis
A conventional angiogram demonstrated a direct carotid-cavernous fistula (CCF).

Treatment
Failure of a stent placement led to the definitive transvenous coil embolization.

Related reports
Unforeseen device failure occurs. Experiences in this regard should be reported.

Term explanation
Covered-stent: No flow is allowed within the struts of the stent, impermeable.

Experiences and lessons
Tortuous vasculature may prevent smooth navigation of rigid devices.

Peer-review
This was described as an interesting manuscript that reviews treatment options of a CCF, and limitations when a covered stent is planned to be used. The authors' experience in the retrieval of a prematurely deployed covered stent may help the reader if facing a similar case.

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