Published in final edited form as:

Pediatr Radiol. 2015 February ; 45(2): 166–172. doi:10.1007/s00247-014-3138-2.

Comparison of diagnostic performance of CT and MRI for abdominal staging of pediatric renal tumors: a report from the Children's Oncology Group

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Abstract

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Conflicts of interest None

Background—CT and MRI are both used for abdominal staging of pediatric renal tumors. The diagnostic performance of the two modalities for local and regional staging of renal tumors has not been systematically evaluated.

Objective—To compare the diagnostic performance of CT and MRI for local staging of pediatric renal tumors.

Materials and methods—The study population was derived from the AREN03B2 study of the Children's Oncology Group. Baseline abdominal imaging performed with both CT and MRI within 30 days of nephrectomy was available for retrospective review in 82 renal tumor cases. Each case was evaluated for capsular penetration, lymph node metastasis, tumor thrombus, preoperative tumor rupture, and synchronous contralateral lesions. The surgical and pathological findings at central review were the reference standard.

Results—The sensitivity of CT and MRI for detecting capsular penetration was 68.6% and 62.9%, respectively ($P=0.73$), while specificity was 86.5% and 83.8% ($P=1.0$). The sensitivity of CT and MRI for detecting lymph node metastasis was 76.5% and 52.9% ($P=0.22$), and specificity was 90.4% and 92.3% ($P=1.0$). Synchronous contralateral lesions were identified by CT in 4/9 cases and by MRI in 7/9 cases.

Conclusion—CT and MRI have similar diagnostic performance for detection of lymph node metastasis and capsular penetration. MR detected more contralateral synchronous lesions; however these were present in a very small number of cases. Either modality can be used for initial loco-regional staging of pediatric renal tumors.

Keywords

Renal tumors; Staging; Wilms tumor; Diagnosis; Magnetic resonance imaging; Computed tomography; Pediatric

Introduction

The most common clinical presentation of a pediatric renal malignancy is a palpable abdominal mass, typically prompting sonography, the recommended imaging modality for initial evaluation of a suspected renal mass [1, 2]. However, once a renal mass is documented on sonography, cross-sectional imaging with CT or MRI to further evaluate the abdominal cavity is considered standard of care in North America and is mandatory in the current renal tumor trials of the Children's Oncology Group. Although CT is the most commonly used imaging modality for initial staging of pediatric renal tumors because of its wide availability, short scan duration and ability to simultaneously evaluate the lungs, some institutions use MRI to evaluate the abdomen because of its lack of ionizing radiation and better soft-tissue contrast, and some institutions perform both CT and MRI. At this time there are no data to compare the diagnostic performance of CT vs. MRI for preoperative local staging of pediatric renal malignancies.

The purpose of this retrospective project was to compare the diagnostic performance of CT and MRI in preoperative loco-regional staging of pediatric renal tumors.

Materials and methods

The cohort for our retrospective study was derived from the ongoing renal tumors classification, biology, and banking study of the Children's Oncology Group (COG) (AREN03B2). The study is approved by the institutional review boards of all participating institutions and is compliant with the Health Insurance Portability and Accountability Act. Written informed consent was obtained from all subjects prior to enrollment in AREN03B2. Per the study protocol, all children and young adults (<30 years) with a first-time diagnosis of a renal tumor are eligible for this ongoing study. At the time of enrollment the institution is required to submit a contrast-enhanced CT or contrast-enhanced MRI study of the abdomen and pelvis for central imaging review. Local institutions are also required to submit operative notes and pathology slides from biopsy or nephrectomy specimens for central review by the study surgeons and pathologists.

As of April 5, 2012, a total of 3,108 people had been enrolled in AREN03B2. The inclusion criteria for this retrospective review were children with renal tumors who had undergone baseline imaging with both CT and MRI prior to and within 30 days of surgery (partial or complete nephrectomy). No chemotherapy was administered between the first imaging study and surgical evaluation. Baseline imaging with both CT and MRI had been performed in 182/3,108 cases. Thirty-four of these 182 had undergone a renal biopsy only at initial evaluation, and 12 had incomplete surgical or pathology data submitted for central review. These 46 cases were excluded from review for lack of an adequate reference standard, resulting in a sample size of 136. Of these 136, 102 had imaging data with both CT and MRI available for central review at the time of this retrospective review. Imaging data were found to be incomplete in 34 cases for the following reasons: non-availability of CT or MRI images at time of this retrospective review in 15, only non-contrast CT of abdomen in 10, only postoperative CT of abdomen 2, only operative MRI of abdomen 4, and limited non-diagnostic MRI studies in 3. Only patients with CT and MRI performed within 30 days of each other and with maximum time interval of 30 days between first cross-sectional abdominal imaging and surgery were included in the analysis, leaving a total of 82 patients in the analytic cohort.

Two pediatric radiologists, each with 9 years of post-fellowship experience, reviewed the CT and MRI scans of these 82 cases in consensus. The radiologists were blinded to local radiology reports, all other imaging studies for the patients, and the surgical and pathological findings at the time of the review. All CT scans were read in consecutive order of chronological case number by the two radiologists, followed by batch reading of the MRIs so as to avoid recall bias from the previously reviewed imaging.

Each case was evaluated for the presence or absence of the following imaging features. Capsular penetration was considered to be present if there was a focal bulge or protrusion in the mass and absent if the margins of the mass were smooth and well-defined (Fig. 1). Retroperitoneal lymph nodes were considered to be involved if they met the criteria of size of 1 cm in the short axis [3] (Fig. 2). A discrete filling defect in the renal vein or inferior vena cava in association with distension of the vessel was considered to be a tumor thrombus. If the vessel could not be delineated because of compression by a surrounding

mass, venous thrombus was considered to be absent for the purpose of this study [4]. Tumor rupture was considered to be present if there was ascites beyond the cul-de-sac, extra-capsular retroperitoneal fluid, or fat stranding around the kidney, with ascites being most predictive of rupture [5]. Contralateral synchronous lesions were defined as non-cystic lesions of any size in the contralateral kidney [6] (Fig. 3).

The surgical and pathological findings at central review were considered the reference standard for all imaging findings evaluated. Presence or absence of capsular penetration, lymph node involvement, and tumor thrombus was determined at central pathology review of the renal mass, surgically sampled lymph nodes, and renal vein or inferior vena cava, respectively. Rupture was evaluated by the central surgical review as positive if the operative note documented the presence of hemorrhagic ascites, peritoneal implants or capsular breach found at the time of laparotomy. If tumor rupture occurred intra-operatively this was not classified as tumor rupture for the purpose of this study.

The sensitivity and specificity of CT and MRI in detecting each criterion of interest (capsular penetration, lymph node involvement, venous extension and preoperative tumor rupture) and 95% confidence intervals (CIs) were calculated by comparing imaging findings with the surgical or pathology review results as the reference standard. The confidence intervals were computed according to the continuity-corrected efficient-score method from Newcombe [7, 8] because the normal approximation does not work well when the proportion is very small or large, as is ideally the case with sensitivity and specificity. The McNemar two-sided test was used on the CT and MRI paired data for each patient to test the null hypothesis of equality of the sensitivity and specificity of CT and MRI [9, 10]. All analyses were performed using SAS® version 9.2 (SAS Institute, Cary, NC).

Imaging technique and image evaluation

In the AREN03B2 study protocol, all institutions are required to perform abdomen and pelvis imaging with either a contrast-enhanced CT or a contrast-enhanced MRI scan [3]. The guidelines for CT abdomen and pelvis are maximum slice thickness of 5 mm with intravenous bolus timed for the portal venous phase. The guidelines for MR abdomen and pelvis are as follows: slice thickness 5 mm or less, fat-suppressed T2-weighted images in at least two planes, pre-contrast T1-weighted image in at least one plane, and post-contrast T1-weighted images with fat saturation in two planes.

Results

The age range for the study cohort was 31 days to 19.4 years (median 3.9 years, mean 4.9 years). There were 47 girls and 35 boys. The mean time interval between the CT and MRI was 2.6 days with a standard deviation of 4.3 days. The mean time interval between first imaging study (CT or MRI) and surgery was 6.0 days with a standard deviation of 6.4 days. All submitted CT scans had been performed with intravenous contrast administration in the portal venous phase with slice thickness of 5 mm or less, and 53/82 subjects had received intraluminal bowel contrast material. In addition, coronal and sagittal reconstructions were available in 51/82 cases, and coronal-only reconstructions in 15/82 cases. Regarding MRI, pre-contrast T1-weighted, fat-saturated T2-weighted and post-contrast fat-saturated T1-

weighted images with slice thickness of 5 mm were available in all cases. Dynamic (multiphase) post-contrast T1-weighted images were available for review in 36/82 cases, while 46/82 cases had single portal venous phase images only. Diffusion-weighted images were available in 11/82 cases.

The final histology based on central pathology review was as follows: Wilms tumor ($n=68$), renal cell carcinoma ($n=5$), cystic nephroma/cystic partially differentiated nephroma ($n=4$), clear cell sarcoma ($n=2$), mesoblastic nephroma ($n=1$), angiomyolipoma ($n=1$) and metanephric tumor ($n=1$). The stage distribution was as follows: stage I ($n=19$), stage II ($n=17$), stage III ($n=24$), stage IV ($n=16$) and stage V ($n=1$). This does not include the five renal cell carcinomas, for which the local staging was as follows: T1 ($n=3$), T2 ($n=1$), T3 ($n=1$); N0 ($n=3$) and Nx ($n=2$).

The diagnostic performance of CT and MRI, compared to reference standard, is summarized in Tables 1 and 2. The sensitivity of CT and MRI for detecting capsular penetration was 68.6% and 62.9% ($P=0.73$), respectively, while specificity was 86.5% and 83.8% ($P=1.0$). Capsular penetration was correctly classified in 68.3% of cases (56/82) by CT and in 64.6% of cases (53/82) by MRI. The sensitivity of CT and MRI for detecting lymph node metastasis was 76.5% and 52.9% ($P=0.22$), respectively, while specificity was 90.4% and 92.3% ($P=1.0$). Lymph node metastasis was accurately classified in 73.2% of cases (60/82) by CT and in 69.5% of cases (57/82) by MRI. Venous extension was present in only 4/82 cases (3 renal vein, 1 inferior vena cava), and accurately classified by CT in 85.4% (70/82) of cases and by MRI in 89% (73/82) of cases. Preoperative tumor rupture was present in only two cases in our cohort and was accurately classified by CT in 85.4% (70/82) of cases and by MRI in 91.5% (75/82) of cases.

CT detected four cases with synchronous contralateral tumor or nephrogenic rest while MRI detected seven cases with contralateral tumor or nephrogenic rest. The size of the contralateral synchronous lesions ranged from 0.2 cm to 2.5 cm (mean 1.0 cm). Contralateral lesions were identified by both CT and MRI in 2/9 cases, leaving 5/9 cases in which a contralateral lesion was detected solely on MRI and 2/9 cases in which a contralateral lesion was detected solely on CT (Fig. 3).

Discussion

Baseline staging is one of the most important prognostic criteria for Wilms tumor, the most common pediatric renal malignancy [8]. Even in patients with stage IV disease, local staging is an important guide for appropriate local treatment, and it is a prognostic factor, with increased risk of abdominal recurrence in patients with advanced local disease [9]. Abdominal staging of pediatric renal tumors can be challenging at initial presentation [1, 10]. The large tumor-to-abdominal-cavity size ratio in pediatric renal tumors makes imaging evaluation of normal structures such as the renal capsule, vessels and adjacent organs challenging. Detailed anatomical information obtained with cross-sectional imaging can be critical to guide the treating surgeon in the operative approach. In North America, the local staging of pediatric renal tumors is based on surgical and pathological evaluation at the time of primary nephrectomy. In Europe, the International Society of Pediatric Oncology (SIOP)

treatment protocol is based on the clinical and imaging appearance of the renal tumor, and surgical or pathological evaluation is performed after initial chemotherapy. McDonald et al. [11] recently described the benefits of CT and MRI in staging Wilms tumor. CT evaluation has the advantage of faster scanning with less frequent need for sedation, and allows for simultaneous evaluation of the lungs. MRI provides better soft-tissue contrast and avoids exposure to ionizing radiation. However, MRI in this patient population almost always requires sedation and a longer duration of anesthesia compared to CT. There is increasing evidence to suggest that exposure of the developing brain to anesthetics may cause long-term neurocognitive impairment [12]. Therefore our study seeks to compare the diagnostic performance of CT versus MRI.

The presence of capsular penetration upstages a Wilms tumor to stage II from stage I. This study shows that CT and MRI have similar diagnostic performance in detection of capsular penetration, with moderate specificity but low sensitivity. This highlights the importance of surgical or pathological staging of Wilms tumor at initial evaluation, as recommended in the renal tumor guidelines of the Children's Oncology Group.

The presence of lymph node metastasis and tumor rupture defines stage III disease and indicates need for abdominal radiation therapy and chemotherapeutic intensification for some children. Lymph node involvement has been shown to be an important predictor of 8-year event-free survival and overall survival for favorable-histology Wilms tumor patients with stage III disease [13]. In our study, using a size criterion of 1 cm in the short axis, CT had higher sensitivity than MRI for detection of lymph node metastasis, though the difference was not statistically significant. We believe that a wider variation in the quality of MRI scans from different institutions, variable slice thickness, variable sequences, and scan parameters used likely accounted for the lower sensitivity of MRI for detection of lymph node disease.

Synchronous bilateral renal lesions can be present in approximately 5% of patients at initial presentation [8]. Presence of a contralateral renal lesion in a child with Wilms tumor can change the stage and initial management of the patient, indicating a role for a renal-sparing approach without up-front surgery. The detection of contralateral renal lesions is important at baseline imaging because routine intra-operative exploration of the contralateral kidney is no longer recommended based on the results of National Wilms Tumor Study-4 [9, 14]. MRI detected more synchronous contralateral lesions than CT in our study. In the two cases in which a synchronous lesion was detected only on CT, the post-contrast MR images were less than optimal because of poor contrast bolus in one case and because of lack of coronal and sagittal sections in another case with failure to show an exophytic lesion at the inferior pole. Superior soft-tissue contrast of MRI compared to CT, even on a non-contrast study, and better characterization of soft tissues from availability of multiple sequences that provide structural and functional information (e.g., diffusion-weighted imaging) likely account for increased sensitivity of MRI for detection of small synchronous lesions. MRI is the preferred imaging modality in the current Children's Oncology Group trials for children with bilateral Wilms tumor or conditions that predispose to bilateral Wilms tumors; MRI is preferred in these trials because of its lack of ionizing radiation and better soft-tissue contrast. However, because of the small numbers of patients with multiple lesions in this

study, no definitive conclusions can be made here. Further evaluation with more subjects, uniform MRI scan parameters, and incorporation of state-of-the-art techniques, such as diffusion-weighted imaging, is needed to determine whether MRI offers a clear advantage.

Our study has several limitations. First, in spite of drawing a study sample from a large cohort of patients enrolled in a multi-institutional study that has been open since March 2006, the number of patients that met our eligibility criteria for imaging with both modalities was relatively small because the AREN03B2 protocol requires imaging with either modality. The presence of tumor thrombus in the inferior vena cava, obvious signs of preoperative tumor rupture, or synchronous bilateral tumors can lead the treating oncologist or surgeon to decide on upfront biopsy and pre-nephrectomy chemotherapy, which potentially explains the small number of cases with these findings in our cohort, because all patients with upfront biopsy were excluded from this study for lack of an adequate reference standard.

Second, there was marked variability in the quality of MRI scans received over the course of the last 7 years from >200 institutions participating in trials of the Children's Oncology Group. For example, multiphase post-contrast images were available in less than 50% of cases and diffusion-weighted images of the abdomen were available in less than 15% of cases. In a multi-institutional study like this, it is not possible to compare state-of-the-art CT to state-of-the-art MRI; however we have provided comparison of standard-of-care CT to standard-of-care MRI.

Third, though we used central review of the local operative report as the reference standard for preoperative tumor rupture, this is dependent on the detail of documentation provided by the institutional surgeon. For example, three cases that were classified as positive for preoperative tumor rupture by CT/MRI in our study were considered negative for rupture by the reference standard because the surgical review had classified them as intra-operative rather than preoperative rupture based on the documentation provided in the local surgical note.

Conclusion

In our study, both CT and MRI had high specificity but relatively low sensitivity in detection of capsular penetration and lymph node metastasis. Though MRI detected more synchronous lesions than CT, no significant difference was demonstrated in this study. Given the similar diagnostic performance of CT and MRI in local evaluation of pediatric renal tumors, we recommend that either modality be used for initial staging based on institutional expertise, need for anesthesia, and concerns regarding cost, ionizing radiation and side effects of anesthesia. The two modalities can be substituted to avoid repeated exposure to ionizing radiation.

Acknowledgments

Research was supported by grants U10 CA98543 and U10 CA98413 from the National Institutes of Health to the Children's Oncology Group, and by grant CA29511 from the National Institutes of Health to the Quality Assurance Review Center (QARC).

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Fig. 1. Capsular penetration of Wilms tumor in a 7-year-old boy. Axial CT (**a**) and MRI (**b**) images show focal protrusion (*arrows*) of the renal mass beyond the renal capsule. This was pathologically confirmed to be capsular penetration

Fig. 2. Lymph node metastasis secondary to Wilms tumor in a 4-year-old boy. Axial CT (**a**) and MRI (**b**) images show enlarged retroperitoneal lymph node (*arrow*). Pathology confirmed lymph node metastasis, indicating stage III disease and a need for abdominal radiation

Fig. 3. Contralateral synchronous lesion in a 6-month-old girl with recently diagnosed Wilms tumor. Axial CT (**a**) and T2-weighted MRI (**b**) images. MRI shows a 1.2-cm T2-hyperintense lesion in the superior pole of the left kidney (*arrow*) which may represent a nephrogenic rest vs. contralateral Wilms tumor. This would upstage the patient to stage V. The lesion is poorly visualized on CT and was not detected prospectively on CT

Table 1
Cross-tabulation of central pathology or surgical review and CT results. CI confidence interval

		Central pathology/surgical review		
		Yes	No	Indeterminate
CT result for capsular penetration	Penetrated	24	5	5
	Intact	11	32	5
	Total	35	37	10
		Sensitivity: 24/35 = 68.6%; 95% CI: 50.6%, 82.6% Specificity: 32/37 = 86.5%; 95% CI: 70.4%, 94.9%		
CT results for lymph node involvement	Positive	13	5	2
	Negative	4	47	11
	Total	17	52	13
		Sensitivity: 13/17 = 76.5%; 95% CI: 49.8%, 92.2% Specificity: 47/52 = 90.4%; 95% CI: 78.2%, 96.4%		
CT results for venous extension	Inferior vena cava	1	0	0
	Renal vein	0	0	0
	No	0	3	5
	Total	1	3	5
		Sensitivity: 1/4 = 25.0%; 95% CI: 1.3%, 78.1% Specificity: 69/73 = 94.5%; 95% CI: 85.8%, 98.2%		
CT results for tumor rupture	Yes	1	8	1
	No	1	69	2
	Total	2	77	3
		Sensitivity: 1/2 = 50.0%; 95% CI: 2.7%, 97.3% Specificity: 69/77 = 89.6%; 95% CI: 80.0%, 95.1%		

Table 2
Cross-tabulation of central pathology or surgical review and MRI results. *CI* confidence interval

		Central pathology/surgical review		
		Yes	No	Indeterminate
MRI results for capsular penetration	Penetrated	22	6	5
	Intact	13	31	5
	Total	35	37	10
Sensitivity: 22/35 = 62.9%; 95% CI: 44.9%, 78.0% Specificity: 31/37 = 83.8%; 95% CI: 67.3%, 93.2%				
MRI results for lymph node involvement	Positive	9	4	2
	Negative	8	48	11
	Total	17	52	13
Sensitivity: 9/17 = 52.9%; 95% CI: 28.5%, 76.1% Specificity: 48/52 = 92.3%; 95% CI: 80.6%, 97.5%				
MRI results for venous extension	Inferior vena cava	1	0	0
	Renal vein	0	0	1
	No	0	3	4
	Total	1	3	5
Sensitivity: 1/4 = 25.0%; 95% CI: (1.3%, 78.1%). Specificity: 72/73 = 98.6%; 95% CI: (91.6%, 99.9%).				
MRI results for tumor rupture	Yes	1	3	1
	No	1	74	2
	Total	2	77	3
Sensitivity: 1/2 = 50.0%; 95% CI: 2.7%, 97.3% Specificity: 74/77 = 96.1%; 95% CI: 88.3%, 99.0%				