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Feasibility of a reduced field-of-view diffusion-weighted (rFOV) sequence in assessment of myometrial invasion in patients with clinical FIGO stage I endometrial cancer

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Abstract

Purpose—To compare the clinical usefulness of reduced field-of-view diffusion-weighted imaging (rFOV) with other imaging techniques in determining the depth of myometrial invasion (DMI) in endometrial cancer.

Materials and Methods—In this prospective study we reviewed 3-Tesla Magnetic resonance images of 51 patients with Clinical stage I endometrial cancer who underwent total abdominal hysterectomy with bilateral salpingoophorectomy within 3 days after imaging. rFOV with apparent diffusion coefficient reconstruction was obtained in three standard planes followed by sagittal T2weighted images and 3 dimensional dynamic T1-weighted (T2WI) and contrast-enhanced imaging (DCE MRI). Two radiologists with expertise in imaging gynecologic cancers evaluated images independently. The DMI was recorded on imaging and correlated with surgical pathology results. Sensitivity, specificity, positive predictive value, negative predictive value, and accuracy for DMI were calculated (<50% vs>50%).

Results—Compared with sagittal T2WI + DCE MRI, rFOV imaging yielded greater specificity (82.2% vs 90.0%, positive predictive value (42.8% vs 60.0%), and accuracy (84.0% vs 92%) for DMI determined by reader 1 and greater the sensitivity (83.3% vs 100%) for DMI determined by reader 2. The error of measurement of DMI as a continuous variable in mm did not

differ significantly between the rFOV and pathology results ($p < 0.21$). However there was a statistically significant difference for the DMI measured on the dynamic sequence. The DMI on DCE was greater than that seen on pathology at $p = 0.02$.

Conclusion—rFOV can be used to assess DMI in clinical stage I endometrial cancer.

Keywords

Diffusion; rFOV; DCE MRI; T2 weighted; MRI; depth of myometrial invasion and Stage I endometrial cancer

Introduction

Endometrial carcinoma is the most common female pelvic malignancy in the developed countries and the fourth most common malignancy in the females in Europe (1). The cumulative risk of developing endometrial cancer worldwide is 14.7% and the estimated cumulative risk of mortality from this cancer is 1.8% (3). The prognosis of patients with endometrial carcinoma depends on multiple factors including the tumor grade, depth of myometrial invasion (DMI), lymphovascular space invasion, cervical stromal invasion, tumor histology, and, most importantly, the presence of metastatic disease to lymph nodes (5–7). The risk of lymph node metastases depends on the DMI and patients with $>50\%$ myometrial invasion have a significantly higher risk for developing lymph node metastases (8). Most patients present clinically with postmenopausal bleeding and therefore are typically diagnosed with early stage disease limited to the uterus without evidence of metastases (9). However, about 15% of patients with clinical stage I tumors may in fact have nodal metastatic disease (8, 10). For that reason, the standard treatment for endometrial cancer includes pelvic and paraaortic lymphadenectomy.

However, lymphadenectomy is associated with significant morbidity including lymphocele formation and chronic lymphedema. The overall frequency of such complications related to surgical staging ranges between 5.9–24% (11, 12). As only 15% of patients with endometrial cancer will have metastatic disease in the lymph nodes, performing lymphadenectomy in all patients with endometrial cancer would subject 85% of patients to unnecessary lymphadenectomy and its associated risks (11). Determining which patients are at high risk for nodal disease is of utmost importance for gynecologic oncologists as this may help spare patients from unnecessary lymphadenectomy. Intraoperative frozen section has been used to measure DMI and thereby determine the risk for lymph node spread (8). Many clinicians, however, have sought radiologic tools to determine DMI (13) preoperatively to better plan surgical procedures, as well as counsel and manage patients with newly diagnosed endometrial cancer.

Pelvic magnetic resonance imaging (MRI) has been the preferred imaging tool for preoperative staging of gynecologic malignancies such as endometrial carcinoma due to its high soft-tissue contrast (14). However, recent data suggest that MRI has certain accuracy limitations in detecting deep myometrial invasion or cervical involvement in patients with endometrial carcinoma, even with currently available sequences such as T1 post contrast and T2weighted images (15, 16).

Diffusion-weighted MRI (DWI) is based on differences in diffusion and motion of water molecules. It has been used as an adjunct to conventional MRI for the preoperative staging of endometrial carcinoma and to measure DMI as well as assess tumor stage (17) and tumor grade (18). The most widely used DWI technique is based on single-shot echo planar imaging (ssEPI), which has the advantage of freezing motion that would otherwise lead to large phase errors and image ghosting with a multishot technique. However, ssEPI is very susceptible to image distortion and artifact from resonance offsets or chemical shift due to the long echo train used for phase encoding and the resultant low bandwidth per pixel along the phase encoding direction. Recently, a reduced field of view (rFOV) single-shot echo planar imaging (ssEPI) technique called optimized and constrained undistorted single shot (FOCUS; GE Healthcare, Waukesha, WI) was described by using a 2D spectral-spatial excitation radiofrequency pulse that limits the signal to a small region of interest (19). For the same spatial resolution, rFOV uses a shorter echo train and thus can be performed without signal wrapping in the phase encoding direction and resulting in reduced image distortion and fewer artifacts (19, 20). The purpose of our study was to prospectively assess the clinical usefulness of the rFOV imaging technique at 3T for the preoperative evaluation of endometrial cancer.

Materials and Methods

Patients

This prospective study was approved by the local Institutional Review Board. Written informed consent was obtained from all participants. From October 4, 2012 through June 27, 2013, 58 consecutive patients with clinical stage I endometrial cancer as determined by physical exam (21) underwent 3T MRI, 1–3 days prior to total abdominal hysterectomy with bilateral salpingoophorectomy with lymph node sampling and dissection as per our institutional protocol. Patients with cervical invasion were excluded from this study because these patients did not undergo surgery. Seven patients were excluded from the final analysis. Five (9%) of 56 patients were excluded due to disease outside the uterus (not clinical stage I) (cervix (n=3), vagina (n=1), peritoneum (n=1)) seen on MRI. One patient became claustrophobic after entering the MRI scanner and one was too large to fit into the scanner and could not complete the DCE MRI and rFOV sequences. Thus, a total of 51 consecutive patients were evaluated in this study. Neither chemotherapy nor radiation therapy was given to the patients before surgery.

Technique

MRI was performed on a 3T whole-body MRI system (Signa; GE Healthcare, Waukesha, WI) operating on the HDxt 16.0 platform. All the MRI studies used body coil transmission and an eight-channel phased array pelvic radiofrequency coil for signal reception. Unenhanced axial T1-weighted images (T1WI), sagittal and axial T2WI, sagittal 3D dynamic T1-weighted contrast-enhanced images (DCE MRI), and post contrast axial T1WI were obtained following administration of intravenous gadolinium. Dynamic images were acquired continuously over a period of 9 minutes. Vaginal gel was instilled in all patients prior to scanning. All patients were scanned on the same 3T scanner and by the same technologist who was trained to do these studies.

Prior to administration of intravenous contrast, high-resolution rFOV images were obtained in three orthogonal (axial, coronal and sagittal) planes to evaluate the uterus. The rFOV pulse sequence was provided to us as an investigational prototype from GE Healthcare. The sequence used a 90° two-dimensional echo-planar spectral spatial radiofrequency pulse to excite only the water signal from a rFOV along the slice and the phase encoding directions. Thus no additional fat suppression was needed. Because of the rFOV used for excitation, a much smaller acquisition matrix of 96×48 was used than is typically possible for body imaging without corresponding signal wrapping artifacts in the phase encoding direction. For coronal and axial acquisitions, two b values (0 and 600 s/mm²) were applied along all three gradient directions to obtain the images. For sagittal acquisition, a set of six b values (0, 50, 100, 150, 200, 600) were applied along all three gradient directions. Other imaging parameters of the sequence were: TR/TE = 4500 ms/60 ms, FOV = 18 cm $\times$ 9 cm, slice thickness = 4 mm, number of signal averages = 16 for b = 600 and 4 for all other b-values. A total of 16 slices were acquired in approximately 4 minutes for coronal and axial acquisitions and in approximately 7 minutes for sagittal acquisition. Using the multiple b-value sagittal rFOV DWI images, apparent diffusion coefficients (ADC) maps were calculated using the intravoxel incoherent motion (IVIM) diffusion model. The sagittal and axial T2 weighted Fast Spin Echo sequences were obtained at TR/TE 5500ms/90ms, FOV 24cm, and slice thickness 4mm and each took 5 minutes to acquire. The DCE MRI was acquired in the sagittal plane at TR/TE 4.0ms/2.0ms, FOV 24cm, and slice thickness 4mm, and at a temporal resolution of approximately 13 seconds per phase. The contrast agent and injection followed the standard of care procedures for clinical MRI at our institution (Gadavist, Bayer HealthCare, 0.1 mL/kg body weight at 1cc/second followed by 30cc saline flush).

Image interpretation

Two radiologists (PB and RI), with 15 and 21 years of experience respectively in imaging of patients with gynecologic malignancy, evaluated the T2WI, DCE MRI, and rFOV independently. First, each reader evaluated T2 and DCE sequences independently for DMI in mm. Then both radiologist evaluated T2+DCE independently (22, 23) for $\geq 50\%$ and $<50\%$ DMI prior to any surgical intervention for tumor size and lymph node involvement on the Phillip's iSite diagnostic picture archiving and communication system monitors. The rFOV sequences were evaluated two weeks after initial interpretation of the diagnostic MRI. For evaluation of all the imaging sequences the readers were blinded to the final pathology findings.

The primary endometrial cancer appeared as an intermediate-to-high signal intensity mass compared to normal myometrium on sagittal T2WI, a low signal intensity mass compared to normal myometrium on the sagittal DCE MRI, and high signal intensity on the sagittal rFOV with low signal on the corresponding ADC maps. The early arterial phase at 40 seconds was used to assess for DMI (24). Both readers recorded the largest dimension of the tumor (24) in millimeters (mm) as seen on T2WI and rFOV imaging using electronic callipers on the PACS. To determine the DMI, the thickness of the myometrium from the endometrial surface to the serosal surface was measured in mm on sagittal images in the anteroposterior dimension, perpendicular to the long axis of the uterus. Similarly, the tumor

extending into the myometrium was also measured in mm on all the sagittal sequences in the anteroposterior dimension from the endometrial surface to the tumor myometrial interface. The ratio of tumor depth to myometrial depth was used to determine the percentage of myometrial invasion as 50% or <50%. The size of the tumor was measured on T2WI and rFOV, size was not measured on DCE MRI. The rFOV and ADC maps were used in conjunction to assess for DMI and overall size of tumor. All the measurements were performed with electronic calipers on a standard FDA-approved Phillip's iSite diagnostic picture archiving and communication system monitor.

DMI was then divided into two groups (<50% or 50%). T2+DCE were evaluated in conjunction to determine DMI. The rFOV sequence was separately evaluated with ADC maps to determine DMI. The DMI determined by the two radiologists on rFOV was compared to the DMI measured on T2 and DCE MRI. For assessment of <50% and 50% DMI, rFOV was compared to the reading of T2+DCE MRI.

Lymph nodes were considered metastatic if the short axis diameter was >1 cm or the nodes were centrally necrotic. Lymph nodes that were >1cm on rFOV and showed diffusion restriction with decreased signal on ADC using a cut off value of $0.8 \times 10^{-3} \text{mm/s}^2$ were considered to be metastatic, this criterion was used to increase the specificity of metastatic lymph node detection(25).

Pathology

A pathologist (PR) specializing in gynecologic oncology evaluated the surgical specimens for the size, grade of the tumor, the DMI and lymph node metastases. The pathology results were considered as the reference standard for assessing tumor size, DMI, and lymph node metastases. The pathologist was blinded to the imaging findings.

Statistical analysis

The imaging-based diagnosis (DMI 50% vs. <50%) was compared with the reference standard. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy were estimated for each reader for T2WI, DCE MRI, and rFOV imaging.

DMI was also analyzed as a continuous variable. The error of imaging measurement (defined as the mean difference in mm between imaging and pathology DMI measurements) for each imaging sequence was estimated and analyzed; linear mixed model was used to compare imaging measurement error between readers and between the sequences. The mixed model accounted for correlation between measurements from the same patient. Tukey-Kramer adjustment was used for pairwise comparisons between sequences to control the family-wise type I error rate at 5%.

Shapiro-Wilk's test for normality was used to assess normality of tumor sizes measured by pathology and different modalities. Pathology size did not pass the normality test ($p = 0.04$), therefore, Spearman's correlation test and LOESS trend lines were used to estimate and illustrate the correlation between pathology and imaging with respect to tumor size measurement by reader and sequence. All tests were two-sided and p-values of 0.05 were

considered statistically significant. These statistical analyses were carried out using SAS version 9 (SAS Institute, Cary, NC).

Results

Demographic characteristics and disease stage

The mean age of the patients was 52.4 ± 13 years (range, 29–75 years). On final pathologic examination, 45 patients had DMI <50%, and 6 patients had DMI $\geq$ 50%. Age did not vary significantly between patients with DMI <50% (mean $\pm$ SD, 59.67 ± 9.35 years; range, 23–80 years) and patients with DMI $\geq$ 50% (mean $\pm$ SD, 50.17 ± 8.98 years; range, 59–83 years); $p=0.31$ (Table 1). Grade 1, 2, and 3 diseases were present in 5 patients (10%), 37 (73%), and 9 (18%) patients, respectively.

Although all recruited patients had clinical Stage I tumors, MRI upstaged 2 patients. On MRI, 44 patients had Stage IA disease (DMI < 50%), 5 patients had Stage IB disease (DMI $\geq$ 50%), and 2 patients had Stage IIIC or nodal disease (both had $\geq$ 50% myometrial invasion). One patient with Stage IIIC disease identified by imaging turned out to be a false positive, with no pathological correlation of lymph node metastasis.

On final pathologic examination of hysterectomy specimens (reference standard), 45 patients had stage IA disease, 4 patients had stage IB disease, 2 patients had stage IIIC disease (both had $\geq$ 50% myometrial invasion) and one was prospectively identified on MRI.

DMI

Compared with T2WI plus DCE MRI, rFOV imaging had slightly better accuracy, specificity, and PPV for detection of DMI as determined by reader 1 and better sensitivity as determined by reader 2 (Table 2). (Fig 2, 3 and 4)

The estimated mean error between the readers' interpretation of images for DMI and the pathology results (the reference standard) was higher for DCE MRI (0.9 mm, $p=0.02$) but not for rFOV (0.44 mm, $p=0.21$) and T2WI (0.43 mm, $p=0.34$). There was no difference between the readers for assessment of DMI ($p=0.08$ and $p=0.25$). DCE MRI yielded higher measurement for DMI than for rFOV or T2 when compared to the pathology findings (Table 3). Interaction between reader and modality was not significant for DMI, meaning that the difference between modalities did not depend on the reader and the sequences (Table 3).

False positive results for $\geq$ 50% DMI occurred in our study in one patient who had fibroids and distension of the uterine cavity due to presence blood products (misinterpreted by both radiologist) (Fig4) and in one patient who had adenomyosis (reported by reader 1).

Tumor size

Spearman's correlation coefficient (r) for the correlation between T2WI tumor size and pathologic tumor size results (reference standard) were $r = 0.67$ ($p < 0.0001$) for reader 1 and $r = 0.63$ for reader 2 ($p < 0.0001$) (Fig 2). The correlation coefficients for the correlation between rFOV imaging and pathology results were 0.80 and $r = 0.77$ (both p -values < 0.0001 , Fig 1).

Lymph node metastases

The accuracy, specificity, sensitivity, positive predictive value (PPV), and negative predictive value (NPV) for lymph node metastases were the same for both readers (96%, 50%, 97.96%, 50%, and 98%, respectively) on T2WI and rFOV sequences. Two patients (4%) were observed to have lymph node metastases on pathology; one patient had endometrioid cancer with squamous differentiation and the other had a grade I endometrioid cancer with papillary features. One patient had false negative findings on MRI for lymph node metastases this patient had a 2.7cm tumor and > 50% myometrial invasion (no enlarged lymph nodes were seen on MRI that were >8mm). The small number of lymph node metastases in our study precluded the comparison between MR sequences for detection of lymph node metastases.

Discussion

This study shows that the rFOV sequence was better able to assess DMI than conventional 3D DCE MRI +T2WI. rFOV also performed better than T2WI for measurement of tumor size. The risk of lymph node spread, which in turn affects patient survival depends on several factors, such as tumor grade, tumor size and DMI(8). If the tumor grade is 2, the size of the tumor is <2 cm, and there is <50% myometrial invasion, then complete lymphadenectomy is not advocated by some gynecologic oncologists, including those at our institution (26–28). DMI is considered the most important morphological predictor of lymph node spread in women with endometrial cancer (26, 29). MRI is very helpful in assessing tumor size and DMI as these parameters cannot be determined on physical exam.

A recent meta-analysis suggested that diffusion MRI with a large FOV is equivalent to DCE MRI in assessing DMI (29). However, that analysis did not include evaluation of the new rFOV sequence on a 3T system. Our study suggests that the rFOV sequence had a slightly better accuracy and specificity than DCE MRI in assessing DMI. We also found that tumor size on rFOV correlated better with tumor size with the final pathology than did T2WI tumor size. Our findings for DMI are supported by recent published data using diffusion-weighted whole-body imaging with background body signal suppression when combined with T2WI, demonstrated improved accuracy over DCE MRI alone or T2WI alone in assessing DMI (17).

The combination of T2 and DCE MRI is thought to be helpful in assessing endometrial tumor infiltration into the myometrium from adenomyosis (3). Adenomyosis is considered an independent positive prognostic factor for disease-free survival in patients with endometrial cancer (30). The extension of endometrial cancer into a focal area of adenomyosis is not considered tumor extension into the myometrium, as it mechanically blocks the tumor from extending into the myometrium (30, 31). Therefore if the tumor is extending into an area of adenomyosis on imaging, then the tumor should not be considered to have myometrial involvement. Our small sample size of patients with adenomyosis precluded further evaluation of this phenomenon.

DCE MRI yielded a significantly larger DMI measurement compared with the actual, pathologic DMI, whereas the rFOV and T2WI DMI measurements did not significantly

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differ from the pathologic DMI. This finding is supported by a recent study which showed that the T2WI and diffusion images had a better accuracy for assessment of DMI (32). We speculate that this measurement error is likely related to peritumoral enhancement, which occurs at the hypointense tumor-myometrial interface. Angiogenic factors such as vascular endothelial growth factor can induce new blood vessel formation and is considered to have a prognostic role in Stage I endometrial cancer with associated poor patient outcome (33). The phenomenon of angiogenesis in patients with endometrial cancer occurs where the cancer cells enter the myometrium. This cellular invasion can result in tenfold increase in the mean vascularity at the tumor/myometrial interface (33, 34) and in turn can cause increased enhancement on imaging. The peritumoral enhancement may have resulted in overestimation of the DMI and possibly resulted in the false-positive results in our study. Even a few millimeters of overestimation may change the overall DMI percentage, especially in the setting of large tumors which compress the myometrium. Thus, if DCE MRI is used as the reference standard for measuring DMI, the tumor-free margin will decrease. In the literature, the tumor-free margin and DMI (both in mm) have been proven to be prognostic indicators such that an increase in the tumor free margin or a decrease in DMI is associated with decreased rate of recurrence and better survival in patients (35–37). Thus, measurements based on the DCE MRI may over calculate the DMI which in turn overestimates those patients with 50% myometrial invasion. This overestimation would in turn suggest a higher chance of lymph node metastases. Recent literature suggests that the diffusion sequence provides a more accurate assessment of the DMI than DCE, as peritumoral enhancement from peritumoral edema is not visible on the diffusion sequence, especially at higher b values (38, 39).

Two patients in our study who had lymph node metastases had myometrial invasion of 12 mm and 13 mm, which corresponded to >50% DMI. Two patients, who did not have lymph node metastases had myometrial invasion of 11 and 12 mm and had <50% DMI. These findings indicate that taking into account only the distance of the tumor infiltrating into the myometrium in mm may not be as useful for predicting lymph node status as reported by Lindauer et al (37).

Direct imaging of lymph nodes is not superior to estimating risk for lymph node involvement based on tumor size and DMI. Imaging uses the size of the lymph nodes to predict lymph node metastases. As the cutoff of lymph node size decreases from >1cm to >8mm on imaging; the accuracy decreases due to an increased number of false positive (40, 41).

Tumor size is also a prognostic factor for locoregional and distant metastatic disease (24, 35). According to the Mayo criteria (42), when the primary endometrial tumors are <2 cm, there is a low likelihood of lymph node metastases. The size of the tumor measured with rFOV yielded a better correlation with pathology findings than did the sagittal T2WI sequence.

On rFOV, all tumors had high signal with corresponding low signal on the ADC maps, as well as low signal on the DCE MRI when compared to adjacent myometrium. A recent study suggested that, the endometrial tumor may be isointense to the myometrium on T2WI,

thus not optimally visible, and therefore this sequence may not even be useful to correctly identify the presence of these isointense tumors (32) let alone to assess tumor size. In our study, given the strong correlation between tumor measured by pathology and the good inter-reader agreement on MRI, patients to be precluded from lymphadenectomy could be identified based on the tumor size and DMI with rFOV imaging.

Both readers derived the same high negative predictive value for detection of lymph node metastases. Lymph node metastases were seen in only two patients, both of whom had grade 2 tumors with >50% myometrial invasion. One had a 2.7cm tumor and the other an 8cm tumor.

A limitation of our study was that it was performed at a single institution. Only patients who would undergo surgical resection were included. Since the patients included had clinically Stage I disease most patients did not have lymph node metastases resulting in a very small subset of patients for evaluation of lymphatic spread of disease. In addition, one patient who was not able to fit in the scanner was excluded from the study. It is uncertain how the rFOV sequence will perform in an open-bore magnet, for obese patients.

In conclusion, DCE MRI produced statistically significant errors in measurements of DMI compared with pathology, whereas rFOV and T2WI performed similarly to pathology in assessing DMI; furthermore, rFOV performed better than conventional T2WI in assessing tumor size. Thus, rFOV appears to be a feasible technique for patients with clinical stage I endometrial carcinoma for assessing DMI and tumor size, which are both important prognostic factors for lymph node metastases, tumor recurrence, and metastatic disease. rFOV technique may be particularly helpful in patients who cannot receive intravenous contrast and, furthermore, may help streamline patient care and enable appropriate selection of patients for pelvic and para-aortic lymphadenectomy.

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Fig 1.

Spearman's rank correlation coefficients between T2WI and pathologic results (reference standard) and between rFOV imaging and pathologic results for tumor size.

The solid line is Loess fitted line to show the trend of correlation.

The scale of Spearman's rank correlation coefficients is as follows: 0.00 to 0.19, very weak correlation; 0.20 to 0.39, fair correlation; 0.40 to 0.59, moderate correlation; 0.60 to 0.79, substantial correlation; 0.80 to 1.00, almost perfect correlation.

2a

2a1

2b

2b1

2c

2c1

2d

2d1

Fig 2.

A 52-year-old woman who had abnormal vaginal bleeding and grade 1 endometrial cancer. (a) T2WI sequence shows a mass in the endometrial cavity involving >50% of the myometrium in the anterior lower uterus (arrow). (b) Three-dimensional T1-weighted DCE MRI shows involvement of >50% of the anterior lower myometrium (arrow) and non-enhancing adenomyosis (arrowhead). (c) Sagittal rFOV shows >50% myometrial involvement of the lower uterine segment (arrow). (d) The corresponding apparent diffusion coefficient map shows >50% myometrial involvement (arrow). Fig a1, b1, c1, and d1 show how the depth of myometrial invasion was measured: the black line shows the thickness of the myometrium, and the white line shows the tumor extension in to the myometrium. B: bladder; V: vagina with gel

3a

3b

3c

Fig 3.

A 56-year-old woman with intermittent postmenopausal bleeding and grade 2 endometrial cancer. Sagittal T2WI (a), three-dimensional T1-weighted DCE MRI (b), and rFOV (c) show a tumor (T) in the endometrial cavity. Note subendometrial enhancement on DCE MRI (b). B: bladder; V: vagina with gel

4a

4b

4c

4d

Fig 4.

A 59-year-old woman with vaginal spotting and grade II endometrial cancer. Sagittal T2WI (a) three-dimensional T1-weighted DCE MRI (b), and rFOV (c) show fibroids (F) and the tumor (arrow) in the anterior lower uterus, with superficial myometrial invasion, difficult to see on DCE MRI (b) owing to blood products in the endometrial cavity. The tumor is isointense to the myometrium on DCE and is better seen on rFOV and T2WI (d) The apparent diffusion coefficient map, with M representing blood products. B: bladder; V: vagina with gel, R: rectum

Table 1

Summary of patient age by invasion status. P-value = 0.31 by Wilcoxon rank sum test.

		N	Mean (Range)	SD
Age	Group			
	<50% DMI	45	59.67 (23–80)	9.35
	50% DMI	6	50.17 (59–83)	8.98
	All	51	58.55	13.05

Table 2

Ability to identify $r < 50\%$ and 50%DMI by, T2WI plus DCE MRI and rFOV.

Reader and modality	Percent				
	Accuracy	Sensitivity	Specificity	Positive predictive value	Negative predictive value
Reader 1					
T2WI + DCE MRI	84	100	82.2	42.8	100
rFOV	92	100	90	60	100
Reader 2					
T2WI + DCE MRI	96	83.3	97.8	83.3	97.8
rFOV	98	100	97.8	85.7	100

The rFOV sequence had a better accuracy and positive predictive value for DMI for Reader 1 and had a higher sensitivity for Reader 2.

Table 3
Summary of linear mixed model results estimating error by reader and modalities in assessing DMI.

Endpoint	Factor	variable	Estimated Mean Error Compared with Pathology (mm)	SE	P-value
DMI	* reader	1	0.9	0.51	0.08
		2	0.29	0.25	0.25
	modality	rFOV	0.44	0.35	0.21
		Dynamic	0.92	0.38	0.02
		T2	0.43	0.45	0.34

* This shows the discrepancy in measurement of DMI, based on the reader compared to pathology in mm. SE= Standard Error
Error is defined as the difference between imaging readings assessing DMI and the DMI recorded on pathology (reference standard). For example, when measuring DMI using rFOV images, the mean error was 0.44mm with standard error of 0.35. This difference was not significantly different from zero ($p = 0.21$), i.e. rFOV image measurements were not significantly different from reference standard pathology results for DMI.