Compressed Sensing VIBE – Clinical Applications in the Female Pelvis

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Introduction

MRI has become an increasingly important tool in the diagnosis and assessment of diseases of the female pelvic organs in recent years. In current guidelines, contrast-enhanced MRI of the female pelvis is not only part of the workup for and staging of gynecologic cancers, that is of the uterus, cervix, and ovaries [1–5], but is also recommended for the workup of indeterminate adnexal masses [4] and the pre-therapeutic assessment of leiomyomas [6], whereas contrast-enhanced sequences are currently regarded as optional in patients with endometriosis [7].

In patients with endometrial carcinoma, dynamic contrast-enhanced (DCE) MRI demonstrated similar sensitivity to T2-weighted sequences (T2w), but was more specific for the detection of deep myometrial invasion [8]. While the depth of myometrial invasion is best depicted during the equilibrium phase, that is approximately 2 min 30 s after gadolinium injection, DCE-MRI allows us to determine the presence of uninterrupted enhancement of the subendometrial zone, which is best observed 35–40 s after contrast injection [1]. This information may be important for those patients for whom fertility-sparing treatment is being considered as it can help rule out myometrial invasion, one of the fundamental criteria to approve eligibility for conservative treatment [9]. In patients with adnexal masses, quantifying DCE-MRI heterogeneity may help to characterize adnexal masses, allowing a better distinction between malignant and benign tumors [10]. Furthermore, the quantitative evaluation of tumor angiogenesis (for example, microvascular characteristics) may become increasingly important for predicting and monitoring treatment response in tumor patients receiving anti-angiogenic treatment [11].

Due to the current trade-off between spatial and temporal resolution, conventional dynamic sequences with a temporal resolution in the range of 12–18 seconds only capture the contrast agent dynamics in the different regions of the uterus insufficiently. These sequences allow only qualitative or semi-quantitative analysis, whereas full quantitative analysis is needed for robust assessment. In our opinion, there is great potential for functional assessment of uterine diseases in addition to the purely morphological assessment of the uterus in order to be able to provide detailed clinical recommendations.

In this context, kinetic models are interesting for the assessment of contrast agent dynamics [12]. Quantitative color-coded maps can be used to evaluate vascular permeability and thus vascular quality. Analyses like this, for example, are important for the detection of the hypoxic components of squamous cell carcinoma of the uterus and could contribute to even more individualized therapy in the future, especially when antiangiogenic substances are used for tumor therapy [13]. In addition, studies have shown that quantitative perfusion analysis may provide important information for the grading of endometrial carcinomas and could help to identify patients at increased risk of local recurrence [14, 15].

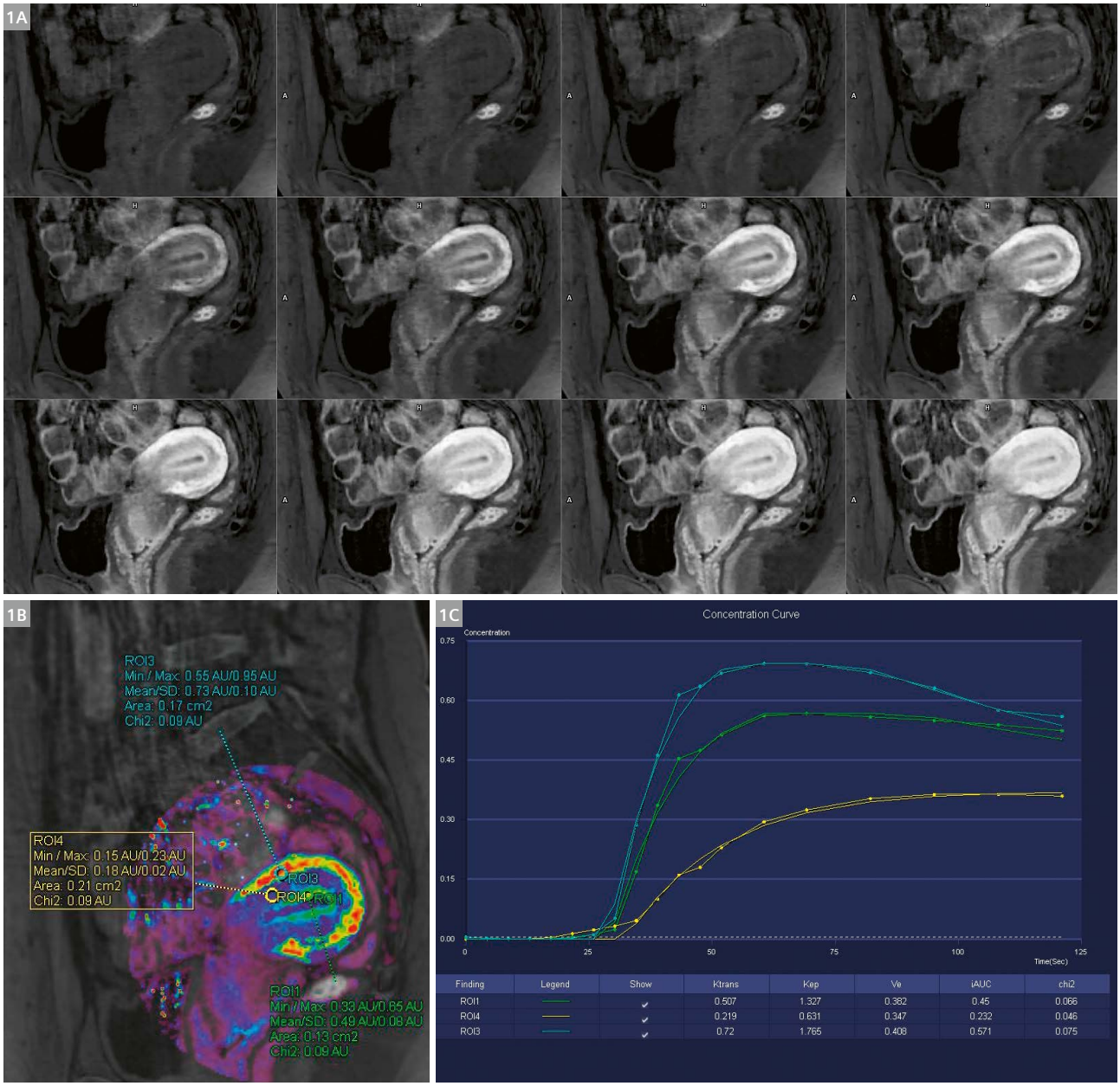
In the context of fertility diagnostics, several studies have shown that there is a link between myometrial perfusion and the cycle phase [16]. In addition, differences in myometrial perfusion between pre- and postmenopausal women were noted.

Compressed Sensing VIBE

The prototypical Compressed Sensing (CS) VIBE sequence[1] supports incoherent *k*-space sampling combined with a joint spatio-temporally regularized reconstruction that is tailored to dynamic imaging. In particular, it allows selection of varying temporal resolutions over the course of the acquisition. For example, in the early phase, where perfusion processes are most evident, a high temporal resolution can be selected (<8 seconds), while in later phases where the entire uterus is already contrasted,

[1]*This work has been done using a WIP version. Compressed Sensing GRASP-VIBE is available as a product.*

a lower temporal resolution can be set (> 10 seconds). With a temporal resolution of < 8 seconds, it is possible to separate the different regions of the uterus with more accuracy than with conventional sequences and the datasets can be used to generate color-coded, quantitative perfusion maps (Fig. 1). Furthermore, the sequence acquires a navigation signal along with the imaging data and more refined reconstruction algorithms can be used for motion artifact reduction. An initial fast, so-called 'hard-gated' reconstruction is based on a fixed fraction ('gating acceptance') of phase-encoding steps for each timepoint and reconstructs the dominant motion state. Another, more elegant method is the motion-state-resolved reconstruction. Using this technique, motion states are bundled, which contributes to an even more advanced artifact reduction (Fig. 2). The number of motion states selected can be flexibly adjusted. In the application presented here, 6 motion states were set.

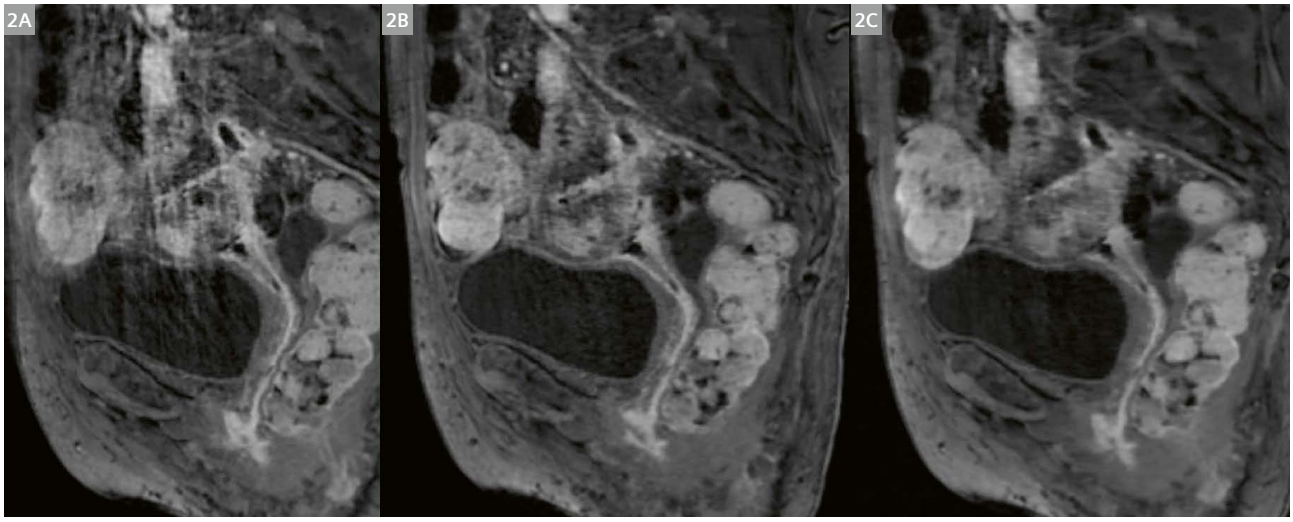


1 Images of a 28-year-old patient with a retroflected uterus. Thanks to the high temporal resolution, CS VIBE allows a detailed morphological analysis of the contrast dynamics in the different zones of the uterus **(1A)**. At the same time, color-coded perfusion maps can be generated using a two-compartment Tofts model (**1B**; here K^{trans}), and various quantitative perfusion parameters (for example, to assess the capillary leakage) and enhancement curves **(1C)** can be evaluated.

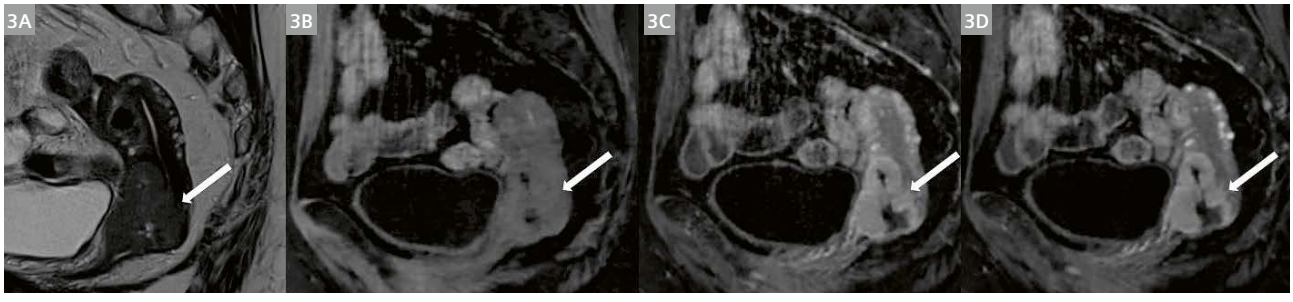
Experience in clinical routine

Compressed Sensing VIBE has proven to be superior to the conventional VIBE thanks to multiple features, which will be discussed in more detail below. In patients with malignant uterine tumors, the sequence may improve the evaluation of tumor infiltration depth thanks to its ability to clearly show the anatomical distinctness of the uterine regions (Fig. 3). In the future, this could allow more accurate T-staging with clinical implications for the therapeutic management of patients. The new sequence might also be beneficial in benign gynecological disease such as leiomyomas and teratomas (Figs. 4, 5). In teratomas, for example, the contrast agent dynamics in Rokitansky nodules was clearly recognizable (Fig. 5). In the evaluation of leiomyomas, the degree of vascularization could be better estimated and feeding arteries better depicted (Fig. 4). In addition, non-vascularized necrotic components within the lesions might be better delineated. In the diagnostic workup of patients with deep infiltrating endometriosis, the depth of infiltration and, in particular, the presence and extent of rectal wall invasion is one of the key criteria for the therapeutic approach. Based on our preliminary experience, CS VIBE might increase diagnostic confidence in this patient population (Fig. 6).

The disadvantage of CS VIBE compared to the conventional VIBE was an occasionally slightly lower lesion contrast. These differences in contrast are particularly due to the different flip angles. For the standard VIBE, a flip angle of 30° was set, while CS VIBE used a lower flip angle of 10° as is usually the case for DCE imaging owing to SNR limitations.



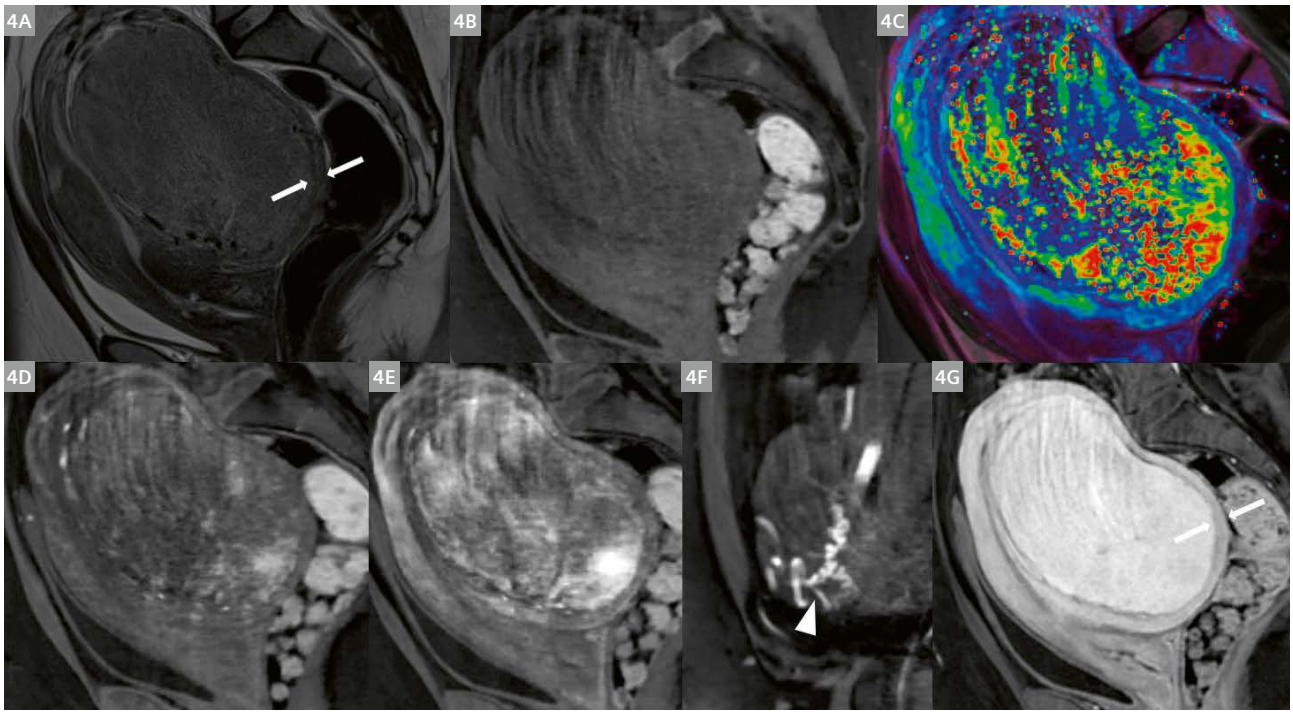
2 Images of a patient with hysterectomy. The contrast enhancement of the vaginal lining in the early arterial phase can be delineated. The hard-gated reconstruction **(2A)** shows prominent vertical motion artifacts along the abdominal wall. Two different motion states **(2B, 2C)** of the same contrast phase are seen on the right. Motion artifacts are significantly mitigated compared to the hard-gated reconstruction.



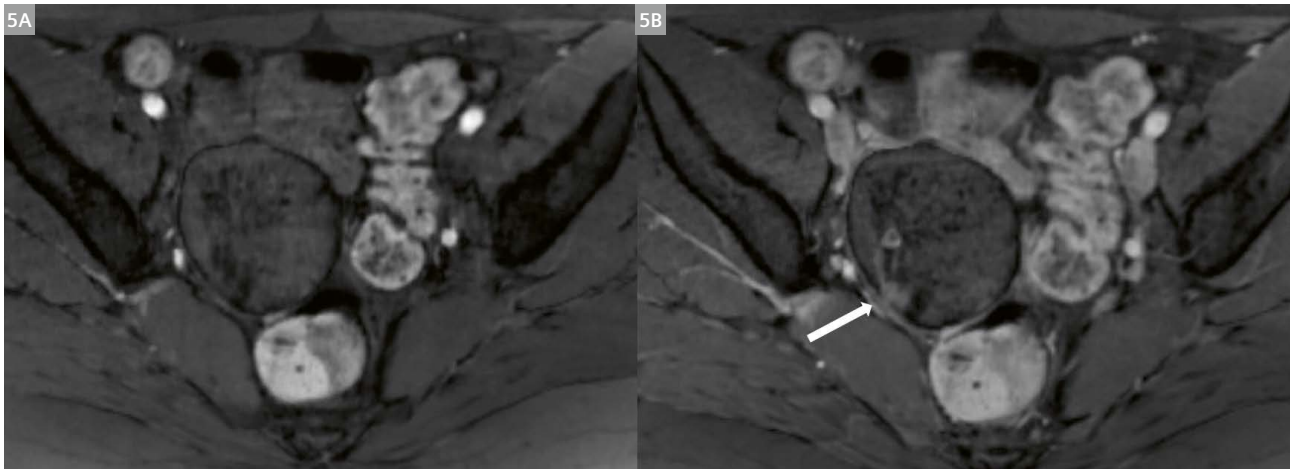
3 Images of a 51-year-old woman with bulky disease in cervical carcinoma with infiltration of the proximal vagina and parametrial involvement (FIGO IIb). The tumor can be delineated both in the sagittal T2 BLADE **(3A)** and on the native CS VIBE **(3B)**, but is best demarcated in the contrast-enhanced phases **(3C, 3D)**. Post-biopsy susceptibility artifacts are visible in the center.

In addition, we had the impression that, when compared to the hard-gated reconstruction, in some cases, the artifact reduction with the motion-state-resolved reconstruction led to sharp organ boundaries, but to a slightly diminished distinctness of the different zones of the uterus.

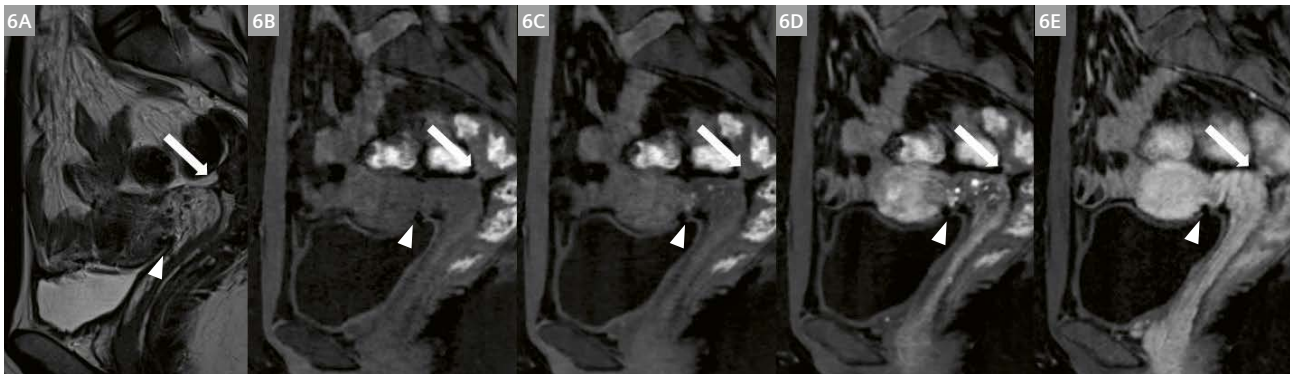
The additional diagnostic benefit of the quantitative color-coded perfusion maps is currently being evaluated in dedicated studies and cannot yet be conclusively assessed.



4 Images of a 30-year-old patient with a large intramural uterine leiomyoma **(4A, 4B)**. Heterogeneous enhancement is seen in early contrast-enhanced images, which is concordant with the color-coded K^{trans} map **(4C-E)**. Dilated feeding vessels are also nicely depicted in early phases **(4F)**. A myometrial stripe is best observed in the equilibrium phase, which is important for surgical planning **(4G)**. Vertical motion artifacts of the hard-gated reconstruction are depicted, but do not interfere with the interpretability of the imaging material.



5 Images of a 26-year-old patient with a mature teratoma of the right ovary. In the early arterial phase **(5A)** of the fat-saturated CS VIBE, fatty tissue components are particularly recognizable. In a later phase, enhancement of the Rokitansky nodule can be clearly depicted.



6 Images of a 30-year-old patient with endometriosis. Both in the sagittal T2w BLADE **(6A)** and in the non-contrast **(6B)**, arterial **(6C)**, venous **(6D)**, and equilibrium phase **(6E)**, infiltration of the anterior rectal wall is clearly visible (arrows). Moreover, due to a history of C-section, postoperative susceptibility artifacts in the lower anterior uterine segment are seen (arrowheads).

Conclusion

CS VIBE is a highly valuable tool for the diagnostic workup of complex uterine and adnexal pathologies and may facilitate improved staging of tumors and a more accurate evaluation of benign diseases. The additional option of a quantitative perfusion analysis could be of particular importance in the future for the response assessment of malignant tumors in order to estimate the degree of vascularization of treated tumors, and potentially also for the workup of infertility. At the same time, both the hard-gated and motion-state-resolved reconstruction lead to a noticeable reduction of motion artifacts, which in individual cases can contribute to higher diagnostic confidence of the radiologists. Both reconstructions can be performed in a clinically acceptable time using GPU-supported scanners.

References

1 Nougaret S, Horta M, Sala E, et al. Endometrial Cancer MRI staging: Updated Guidelines of the European Society of Urogenital Radiology. Eur Radiol. 2019;29(2): 792-805.
2 Sala E, Rockall A, Kubik-Huch RA. Advances in magnetic resonance imaging of endometrial cancer. Eur Radiol. 2011;21(3): 468-473.
3 Balleyguier C, Sala E, Da Cunha T, et al. Staging of uterine cervical cancer with MRI: guidelines of the European Society of Urogenital Radiology. Eur Radiol. 2011;21(5): 1102-1110.
4 Forstner R, Thomassin-Naggara I, Cunha TM, et al. ESUR recommendations for MR imaging of the sonographically indeterminate adnexal mass: an update. Eur Radiol. 2017;27(6): 2248-2257.
5 Forstner R, Sala E, Kinkel K, et al. ESUR guidelines: ovarian cancer staging and follow-up. Eur Radiol. 2010;20(12): 2773-2780.
6 Kubik-Huch RA, Weston M, Nougaret S, et al. European Society of Urogenital Radiology (ESUR) Guidelines: MR Imaging of Leiomyomas. Eur Radiol. 2018;28(8): 3125-3137.
7 Bazot M, Bharwani N, Huchon C, et al. European society of urogenital radiology (ESUR) guidelines: MR imaging of pelvic endometriosis. Eur Radiol. 2017;27(7): 2765-2775.
8 Wu LM, Xu JR, Gu HY, et al. Predictive value of T2-weighted imaging and contrast-enhanced MR imaging in assessing myometrial invasion in endometrial cancer: a pooled analysis of prospective studies. Eur Radiol. 2013;23(2): 435-449.
9 Fujii S, Kido A, Baba T, et al. Subendometrial enhancement and peritumoral enhancement for assessing endometrial cancer on dynamic contrast enhanced MR imaging. Eur J Radiol. 2015;84(4): 581-589.
10 Thomassin-Naggara I, Soualhi N, Balvay D, et al. Quantifying tumor vascular heterogeneity with DCE-MRI in complex adnexal masses: A preliminary study. J Magn Reson Imaging. 2017;46(6): 1776-1785.
11 Brandao AC, Silva AO. Diseases of the female pelvis: advances in imaging evaluation. Magn Reson Imaging Clin N Am. 2013;21(2): 447-469.
12 Tofts PS, Cutajar M, Mendichovszky IA, et al. Precise measurement of renal filtration and vascular parameters using a two-compartment model for dynamic contrast-enhanced MRI of the kidney gives realistic normal values. Eur Radiol. 2012;22(6): 1320-1330.
13 Hauge A, Wegner CS, Gaustad JV, et al. DCE-MRI of patient-derived xenograft models of uterine cervix carcinoma: associations with parameters of the tumor microenvironment. J Transl Med. 2017;15(1): 225.
14 Ippolito D, Minutolo O, Cadonici A, et al. Endometrial cancer: diagnostic value of quantitative measurements of microvascular changes with DCE-MR imaging. MAGMA. 2014;27(6): 531-538.
15 Haldorsen IS, Gruner R, Husby JA, et al. Dynamic contrast-enhanced MRI in endometrial carcinoma identifies patients at increased risk of recurrence. Eur Radiol. 2013;23(10): 2916-2925.
16 Thomassin-Naggara I, Balvay D, Cuenod CA, et al. Dynamic contrast-enhanced MR imaging to assess physiologic variations of myometrial perfusion. Eur Radiol. 2010;20(4): 984-994.

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