Abstract

Objectives: This study aimed to compare the performance of non–contrast-enhanced magnetic resonance angiography (NCE-MRA) at 1.5 T and 3 T for the visualization of uterine and ovarian arteries (OAs) before uterine artery embolization (UAE).

Methods: Preprocedural pelvic NCE-MRA images of 85 symptomatic patients undergoing UAE for the treatment of uterine leiomyomas were reviewed by two specialists in pelvic MRI. Left and right uterine arteries (UAs) were judged separately and scored on a 5-point scale. Score 5 was the highest, in which the UA could be visualized inside the musculature, forming a peritumoral plexus. Score 1 was the lowest, where visualization was limited to the descending segment. The detection of enlarged OAs was also compared. The Mann–Whitney U and Fisher exact tests were used for statistical analysis. $P < 0.05$ was considered to be statistically significant.

Results: Of the 170 UAs, 110 were classified at 1.5 T and 60 were classified at 3 T. Median (interquartile range [IQR]) score was 3 (IQR: 2–4) for visualization at 1.5 T vs 5 (IQR: 4–5) for 3 T. The scores for UA visualization were significantly higher at 3 T ($P < 0.05$). For enlarged OAs, NCE-MRA at 1.5 T and 3 T visualized 7 and 5 enlarged OAs, respectively; there was no significant difference between the two field strengths ($P = 0.36$).

Conclusions: NCE-MRA performed at 3 T can visualize UAs over a greater range than at 1.5 T. No difference was found regarding the detection of enlarged OAs.

Keywords: Uterine artery embolization, Magnetic resonance angiography, Uterine artery, Leiomyoma, Uterus

Key Points:

- Preprocedural MRA can provide interventional radiologists with valuable information, including the origin and course of the uterine arteries and the existence of collateral feeders to the tumor.
- This study demonstrates the superiority of non–contrast-enhanced MRA performed at 3 T over that performed at 1.5 T in the visualization of the uterine arteries in patients undergoing uterine artery embolization for the treatment of uterine leiomyomas.
- Non–contrast-enhanced MRA is a useful imaging modality for patients with symptomatic leiomyoma undergoing uterine artery embolization in whom contrast administration is unfeasible. If available, it is preferable to perform the examination with a 3 T MR unit rather than a 1.5 T MR unit.

Abbreviations and acronyms:

NCE, Non–contrast-enhanced; MRA, Magnetic resonance angiography; T, Tesla; OA, Ovarian artery; UAE, Uterine artery embolization; UA, Uterine artery; IQR, Interquartile range; true-SSFP, True steady-state free precession; Time-SLIP, Time–spatial labeling inversion pulse; STIR, Short-tau inversion recovery; MIP, Maximum intensity projection; BBTI, Black blood time interval

Introduction

Three-dimensional (3D) pelvic magnetic resonance angiography (MRA) provides useful information for interventional radiologists, and it is often used in planning for uterine artery embolization (UAE). In addition to visualizing the origins of uterine arteries, which is of great value for super-selective catheterization, MRA can also detect enlarged ovarian arteries and reveal anatomical variants, ensuring adequate preprocedural planning [1, 2].

Previous reports have demonstrated the usefulness of gadolinium-based contrast agents to assess the vascularization of leiomyomas before UAE [1-7]. However, the association of these agents with nephrogenic systemic fibrosis in patients with chronic renal disease has raised questions about its use [8]. In our clinical practice, the initial protocol for patients undergoing UAE is a non–contrast-enhanced (NCE) MR study. By assessing NCE-MRA and MR images, we evaluate the suitability of tumors for UAE by checking the caliber, origin, and course of the uterine arteries; the formation of the peritumoral plexus; and the possible existence of a collateral supply such as from an ovarian artery. Furthermore, we consider that performing non-contrast imaging is safer, faster, and more convenient (for patient and operators) than obtaining contrast-enhanced imaging to visualize the vascular anatomy [9].

The MR angiographic technique using true steady-state free precession (true SSFP) combined with time–spatial labeling inversion pulse (Time-SLIP) is a very useful modality for obtaining unenhanced 3D reconstructions of the uterine and tumor vasculature. By using blood as an endogenous contrast material, this technique enables the visualization of bright blood vessels within a target region that has the background signal suppressed [10]. Its use for obtaining 3D-MRA reconstructions of the vasculature in the renal and hepatic regions has progressed substantially [11, 12]. However, regarding the pelvic region, much remains to be clarified.

One aspect to be considered is the magnetic field strength for imaging acquisition. Benefits of 3 T over 1.5 T, such as gain in signal-to-noise ratio and longer T1 relaxation time, can improve vessel-versus-background contrast and should be explored for improving NCE-MRA imaging [10, 13]. Currently, both field strengths have been used in different institutions to visualize the pelvic arterial tree [14], but according to the guidelines for MR imaging of leiomyomas issued by the European Society of Urogenital Radiology (ESUR), there has not yet been any study comparing 1.5 T versus 3 T for imaging of benign uterine lesions [14].

We believe that the twofold increase in magnetic field strength can substantially improve visualization of vessels. To confirm this assumption, we compared preprocedural MRA images from patients undergoing UAE for symptomatic uterine leiomyomas at our institution.

Materials and Methods

Subjects

This research was approved by the institutional review board, and the requirement for informed consent was waived. Data of all consecutive patients (*n* = 88) who underwent UAE for symptomatic uterine leiomyomas at our institution from December 2016 to November 2019 were retrieved from the radiological reporting system. From October 2016 to November 2018, a 1.5 T MR unit (Excelart Vantage powered by Atlas; Canon Medical Systems) was used for image acquisition in our department. In December 2018, the MR machine was replaced by a 3 T unit (Vantage Galan 3T / ZGO; Canon Medical Systems). Of the 88 patients, one patient's MRA was not accessible for evaluation, and two other patients had their preprocedural MRA performed with an MR machine other than the two mentioned previously. Therefore, these three patients were excluded from this study, resulting in 85 patients (mean age, 45 years; range, 36–51 years). The mean number of leiomyomas per patient was 9.7 (range, 1–31), the mean volume of the dominant tumor was 338 cm^3 (range, 2–1562 cm^3), and the mean uterine volume was 820 cm^3 (range, 167–2211 cm^3).

MR protocol

For each patient, the imaging examination was conducted with either the 1.5 T MR unit or the 3 T MR unit, using a pair of phased-array coils (16 channels with 16 elements: Atlas Speeder Body Coil combined with Atlas Speeder Spine Coil; Canon Medical Systems) placed at the front and back of the abdomen. We used our established protocol for preprocedural UAE assessment: sagittal and axial fast-spin echo T2-weighted imaging (T2WI), sagittal T1-weighted imaging (T1WI), sagittal T1WI with fat saturation, diffusion-weighted imaging (b-value = 1000), apparent diffusion coefficient mapping, and non–contrast-enhanced MRA.

Non–contrast-enhanced magnetic resonance angiography

To visualize the uterine arteries selectively, the 3D true SSFP sequence combined with Time-SLIP was used with peripheral-pulse gating. All images were acquired in the axial plane and coronal plane (used for axial multiplanar reconstruction). Short-tau inversion recovery (STIR) pulse was applied for suppression of the fat signal. The Time-SLIP tag was placed from the level of the aortic bifurcation forward, over a range that covered the uterus, in the axial direction. Within this tagged region, the Time-SLIP pulse utilized a slice-selective IR (sIR) pulse that inverts all spins to −180° in the longitudinal magnetization (− Mz). The delay time between the application of Time-SLIP and the start of the main imaging acquisition, referred to as the black blood time interval (BBTI), was set at 1500 ms at 1.5 T and 2000 ms at 3 T. The average time for imaging acquisition was 8 minutes for both scanners. Detailed imaging parameters for both MR units are described in Table 1.

Visual classification of the uterine arteries

Visualization of the uterine arteries was independently scored by two radiologists with 30 years' experience (observer 1: RK) and 9 years' experience (observer 2: HK) in female pelvic imaging, who were blinded to the conventional angiographic images at the time of evaluation. In the event of score disagreement, the final classification was decided by consensus. The left and right uterine arteries were identified, and the course of each was assessed with continual rotation of the 3D reconstructed MRA model of the pelvic arterial tree. In addition, the maximum intensity projection (MIP) was assessed to confirm the classifications. For each exam, the conspicuity of the uterine artery was scored on a 5-point scale: 1, conspicuous descending segment (Fig. 1a); 2, conspicuous transverse segment (Fig. 1b); 3, conspicuous proximal ascending segment (Fig. 2); 4, conspicuous distal ascending segment (Fig. 3); and 5, conspicuous peritumoral plexus (Fig. 3). We created this classification based on the following rationale: the further the segment, the better the accuracy of the exam in visualizing the target artery.

Visualization of enlarged ovarian arteries

All images were evaluated by the same observers with regard to the presence of enlarged ovarian arteries at preprocedural MRA. Images were allocated into four categories according to the presence and location of the visualized enlarged ovarian artery: 1, Left ovarian artery enlarged (Fig. 4); 2, Right ovarian artery enlarged (Fig. 5); 3, Both ovarian arteries enlarged (Fig. 6); and 4, No enlargement of ovarian arteries.

Volume measurement

For each patient, preprocedural sagittal T2-weighted images were imported into the volume analyzer of the Synapse Vincent system (FUJIFILM Medical Co., Ltd.). After a radiologist had delineated the margins of the uterus and the largest tumor in sequential sagittal slices, the program automatically calculated the total volume.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows Version 26 (IBM Corp.). For normally distributed data, we used mean value ± standard deviation. For data not normally distributed, we used median and interquartile range (IQR). The distribution of scores for visualization of uterine arteries was compared using the nonparametric Mann–Whitney U-test. The presence of enlarged ovarian arteries was compared using the Fisher exact test. The significance level was set at $P < 0.05$.

Results

Imaging of 110 uterine arteries was performed at 1.5 T (Group 1), and imaging of 60 uterine arteries was performed at 3 T (Group 2). The median age in Group 1 was 46 years (IQR: 44–47.5 years) and that in Group 2 was 45 years (IQR: 44–48 years). The median age was not statistically different between the two groups ($P = 0.77$). The median number of leiomyomas per patient in Group 1 was 9 (IQR: 5–13) and that in Group 2 was 9.5 (IQR: 3–14). The median number of leiomyomas per patient was not statistically different between the two groups ($P = 0.83$). The median volume of the dominant tumor was 232 cm^3 (IQR: 143–435 cm^3) in Group 1 and 276 cm^3 (IQR: 155–475 cm^3) in Group 2. No significant difference was found between the two groups ($P = 0.55$). The median uterine volume was 768 cm^3 (IQR: 558–1009 cm^3) in Group 1 and 706 cm^3 in Group 2 (IQR: 559–1001 cm^3). Again, these values did not differ significantly between groups ($P = 0.94$).

The median uterine artery visualization score for Group 1 was 3 (IQR: 2–4) vs 5 (IQR: 4–5) for Group 2. The distribution of the highest scores was significantly higher at 3 T than at 1.5 T ($P < 0.05$). A detailed description of the scores is presented in Table 2.

Regarding visualization of enlarged ovarian arteries, seven enlarged ovarian arteries were visualized by MR angiography at 1.5 T. Two were bilateral and three were unilateral (two right side and one left side). At 3 T, five enlarged ovarian arteries were visualized; all were unilateral (four right side and one left side). No statistically significant difference ($P = 0.36$) was found between the performance of 1.5 T and 3 T MR units.

Discussion

This study is the first comparison of pelvic NCE-MRA using true SSFP combined with Time-SLIP for the visualization of uterine and ovarian arteries at 1.5 T and 3 T. Overall, our results suggest that the imaging quality of NCE-MRA at 3 T is superior to that at 1.5 T for preprocedural UAE assessment. This improvement was evident by the visualization of segments further along the uterine artery, such as the distal ascending segment (score 4) and the peritumoral plexus (score 5). These segments were visualized in 16% and 20%, respectively, of the uterine arteries evaluated at 1.5 T, whereas at 3 T, 13% of the uterine arteries were visualized until the distal ascending segment and 73% were visualized until the peritumoral plexus.

Time-SLIP is a variant of arterial spin labeling that balances the blood signal against background suppression within a targeted region to visualize the vessels of interest. By using blood as an endogenous contrast agent and relying on contrast from the T2/T1 ratio, this method generates high-quality vascular images without exposing the patient to ionizing radiation or to risks related to gadolinium-based contrast media. One of the key settings to obtain the highest signal from the target vessels is the adjustment of the delay time between the application of the Time-SLIP pulse and the main acquisition, which is referred to as the black blood time interval (BBTI). This coordination allows the acquisition to begin at the optimal point for acquiring bright blood and suppressed background signal, providing excellent images [10, 12, 15].

Kiguchi and colleagues [16] studied this interval for visualization of the uterine artery using true SSFP with Time-SLIP implemented in an alternating tag on/tag off mode at 3 T. They evaluated the quality of MRA images acquired with four different inversion time values (1200, 1400, 1600, and 1800 ms), and they found that the optimal interval for visualization of uterine arteries at 3 T seemed to be between 1400 and 1600 ms [16]. In our study, the delay time was adjusted to within this range for image acquisition at 1.5 T (1500 ms). At 3 T, we found the best results with the BBTI adjusted to 2000 ms.

With regard to the difference in delay interval selected for imaging acquisition at 3 T, it is important to note that in the study reported by Kiguchi et al [16], among the 20 volunteers who underwent MRI examination, only two presented with uterine leiomyomas. We strongly believe that the presence of uterine tumors in all of our patients has influenced the visualization of uterine arteries in our study, contributing to the different delay interval selected for the best imaging acquisition at 3 T.

Mori and colleagues [17] used time-of-flight combined with sensitivity-encoding and water-excitation techniques at 1.5 T to obtain pelvic NCE-MRA images. By that technique, visualization of the ascending portion of the uterine artery (scores 3 and 4 in our classification) was not possible. However, because in their practice the microcatheter was planned to be inserted into the distal descending portion of the uterine artery, that limitation was acceptable [17]. In our department, we plan for the tip of the microcatheter to be inserted into the proximal ascending portion of the uterine artery beyond the cervico-vaginal branch. Consequently, we took great advantage of this further preprocedural visualization of the target vessels, which allows us to predict the best catheter and approach to be used in each case. Also, visualization of the numerous smaller branches that originate from the uterine artery in its most distal portion often suggested to us that a smaller size of microsphere embolization particles (500–700 µm) would be more likely to provide an effective embolization. The influence that our preprocedural imaging assessment has on the technical aspects of UAE needs further investigation before it becomes an established protocol.

Regarding the visualization of enlarged ovarian arteries, we found no significant difference between the 1.5 T and 3 T images. Kroencke et al [4] reported detection of 18 enlarged ovarian arteries in 90 patients studied (10%) using contrast-enhanced MRA, and Mori et al [17] detected 5 enlarged ovarian arteries in 35 patients studied (7%) using NCE-MRA. Similarly, in our study, NCE-MRA visualized 12 enlarged ovarian arteries in 85 patients (7%).

We acknowledge that our study has limitations. It is a retrospective analysis with a small number of cases, and we compare a different number of subjects in each group, which might under- or overestimate our findings. Therefore, further studies are needed to confirm our results. Also, adapting a 1.5 T protocol to 3 T is subject to a variety of factors. Therefore, in order to obtain the best performance in both scanners, some differences in the parameters were unavoidable. Finally, we acknowledge that by not using a contrast agent, potential information about the tumors is lost, which might limit the generalizability of our study. However, we do believe that our results are of great importance for certain subpopulations of patients undergoing UAE, such as those with contraindications to contrast administration.

In conclusion, our study suggests that non–contrast-enhanced pelvic MRA using true SSFP combined with Time-SLIP performed at 3 T allows visualization further along the uterine artery than at 1.5 T. In this comparison, there was no significant difference regarding the visualization of enlarged ovarian arteries.

References

1 Kirby JM, Burrows D, Haider E, Maizlin Z, Midia M (2011) Utility of MRI before and after uterine fibroid embolization: why to do it and what to look for. Cardiovasc Intervent Radiol 34:705–716

2 Maciel C, Tang YZ, Sahdev A, Madureira AM, Vilares-Morgado P (2017) Preprocedural MRI and MRA in planning fibroid embolization. Diagn Interv Radiol 23:163–171

3 Naguib NN, Nour-Eldin NE, Hammerstingl RM et al (2008) Three-dimensional reconstructed contrast-enhanced MR angiography for internal iliac artery branch visualization before uterine artery embolization. J Vasc Interv Radiol 19:1569–1575

4 Kroencke TJ, Scheurig C, Kluner C, Taupitz M, Schnorr J, Hamm B (2006) Uterine fibroids: contrast-enhanced MR angiography to predict ovarian artery supply–initial experience. Radiology 241:181–189

5 Lee MS, Kim MD, Lee M et al (2012) Contrast-enhanced MR angiography of uterine arteries for the prediction of ovarian artery embolization in 349 patients. J Vasc Interv Radiol 23:1174–1179

6 Naguib NN, Nour-Eldin NE, Lehnert T et al (2009) Uterine artery embolization: optimization with preprocedural prediction of the best tube angle obliquity by using 3D-reconstructed contrast-enhanced MR angiography. Radiology 251:788–795

7 Nikolaidis P, Siddiqi AJ, Carr JC et al (2005) Incidence of nonviable leiomyomas on contrast material-enhanced pelvic MR imaging in patients referred for uterine artery embolization. J Vasc Interv Radiol 16:1465–1471

8 Grobner T (2006) Gadolinium–a specific trigger for the development of nephrogenic fibrosing dermopathy and nephrogenic systemic fibrosis? Nephrol Dial Transplant 21:1104–1108

9 Edelman RR, Koktzoglou I (2019) Noncontrast MR angiography: an update. J Magn Reson Imaging 49:355–373.

10 Miyazaki M, Akahane M (2012) Non-contrast enhanced MR angiography: established techniques. J Magn Reson Imaging 35:1–19

11 Shonai T, Takahashi T, Ikeguchi H, Miyazaki M, Amano K, Yui M (2009) Improved arterial visibility using short-tau inversion-recovery (STIR) fat suppression in non-contrast-enhanced time-spatial labeling inversion pulse (Time-SLIP) renal MR angiography (MRA). J Magn Reson Imaging 29:1471–1477

12 Shimada K, Isoda H, Okada T et al (2009) Non-contrast-enhanced hepatic MR angiography with true steady-state free-precession and time spatial labeling inversion pulse: optimization of the technique and preliminary results. Eur J Radiol 70:111–117

13 Willinek WA, Schild HH (2008) Clinical advantages of 3.0 T MRI over 1.5 T. Eur J Radiol 65:2–14

14 Kubik-Huch RA, Weston M, Nougaret S et al (2018) European society of urogenital radiology (ESUR) guidelines: MR Imaging of leiomyomas. Eur Radiol 28:3125–3137

15 Wheaton AJ, Miyazaki M (2012) Non-contrast enhanced MR angiography: physical principles. J Magn Reson Imaging 36:286–304

16 Kiguchi K, Kido A, Fujimoto K et al (2014) Non-contrast-enhanced MR angiography of uterine arteries with balanced steady-state free precession and time-space labelling inversion pulse: technical optimization and preliminary results. Clin Radiol 69:669–673

17 Mori K, Saida T, Shibuya Y et al (2010) Assessment of uterine and ovarian arteries before uterine artery embolization: advantages conferred by unenhanced MR angiography. Radiology 255:467–475

Figure legends

Figure 1: Images from a 48-year-old woman. Preprocedural 3D NCE-MRA from the 1.5 T MR unit. (A) Score 1: tip of the left uterine artery at the descending segment (arrow). The model was rotated for demonstration of the uterine artery. (B) Score 2: tip of the right uterine artery at the transverse segment (arrow).

Figure 2: Image from a 46-year-old woman. Preprocedural 3D NCE-MRA from the 1.5 T MR unit (oblique view). Score 3: tip of the right uterine artery at the proximal ascending segment (arrowhead). Score 2: tip of the left uterine artery at the transverse segment (arrow).

Figure 3: Image from a 49-year-old woman. Preprocedural 3D NCE-MRA from the 3 T MR unit (oblique view). Score 4: tip of the right uterine artery at the distal ascending segment (arrowhead). Score 5: left uterine artery forming the peritumoral plexus (arrow).

Figure 4: Image from a 42-year-old woman. Preprocedural 3D NCE-MRA from the 3 T MR unit (oblique view). Visualization of enlarged left ovarian artery (arrow).

Figure 5: Image from a 49-year-old woman. Preprocedural 3D NCE-MRA from the 3 T MR unit (oblique view). Visualization of enlarged right ovarian artery (arrow).

Figure 6: Image from a 45-year-old woman. Preprocedural 3D NCE-MRA from the 1.5 T MR unit. Visualization of bilaterally enlarged ovarian arteries. Right ovarian artery (arrow) and left ovarian artery (arrowhead).

Tables

Table 1: Parameters used for NCE-MRA imaging acquisition on 1.5 T and 3 T MR machines.

MR unit	**EXCELART Vantage powered by Atlas**	**Vantage Galan 3T / ZGO**
Field strength (T)	1.5	3.0
Sequence	FFE3D true SSFP	FFE3D true SSFP
Repetition time (ms)	5	4
Echo time (ms)	2.5	2
Flip angle (degree)	120	120
Fat suppression	STIR	STIR
Time interval (TI)	190	250
Number of slices	80	80
Section thickness (mm)	1.5	1.5
Field of view (mm^2)	350 × 350	350 × 300
Matrix	256 × 256 (512 × 512)	256 × 240 (512 × 480)
Segments	1	1
Space order	Swirl	Swirl
Speeder factor	2.2	2
TAG thickness (mm)	250	300
BBTI (ms)	1500	2000
Trigger	Pulse synchrony	Pulse synchrony
Shot interval (s)	5	5

T - Tesla, FFE- Fast field echo, 3D - Three dimensional, true SSFP - True steady state free precession, STIR- Short-tau inversion recovery, BBTI - Black blood time interval.

Table 2: Scores for uterine artery visualization on 1.5 T and 3 T MR machines.

Score	**1.5 T**	**3 T**
1	18 (16%)	0
2	31 (28%)	3 (5%)
3	21 (19%)	5 (8%)
4	18 (16%)	8 (13%)
5	22 (20%)	44 (73%)
Total	110 (100%)	60 (100%)

T - Tesla.

Figure 1A

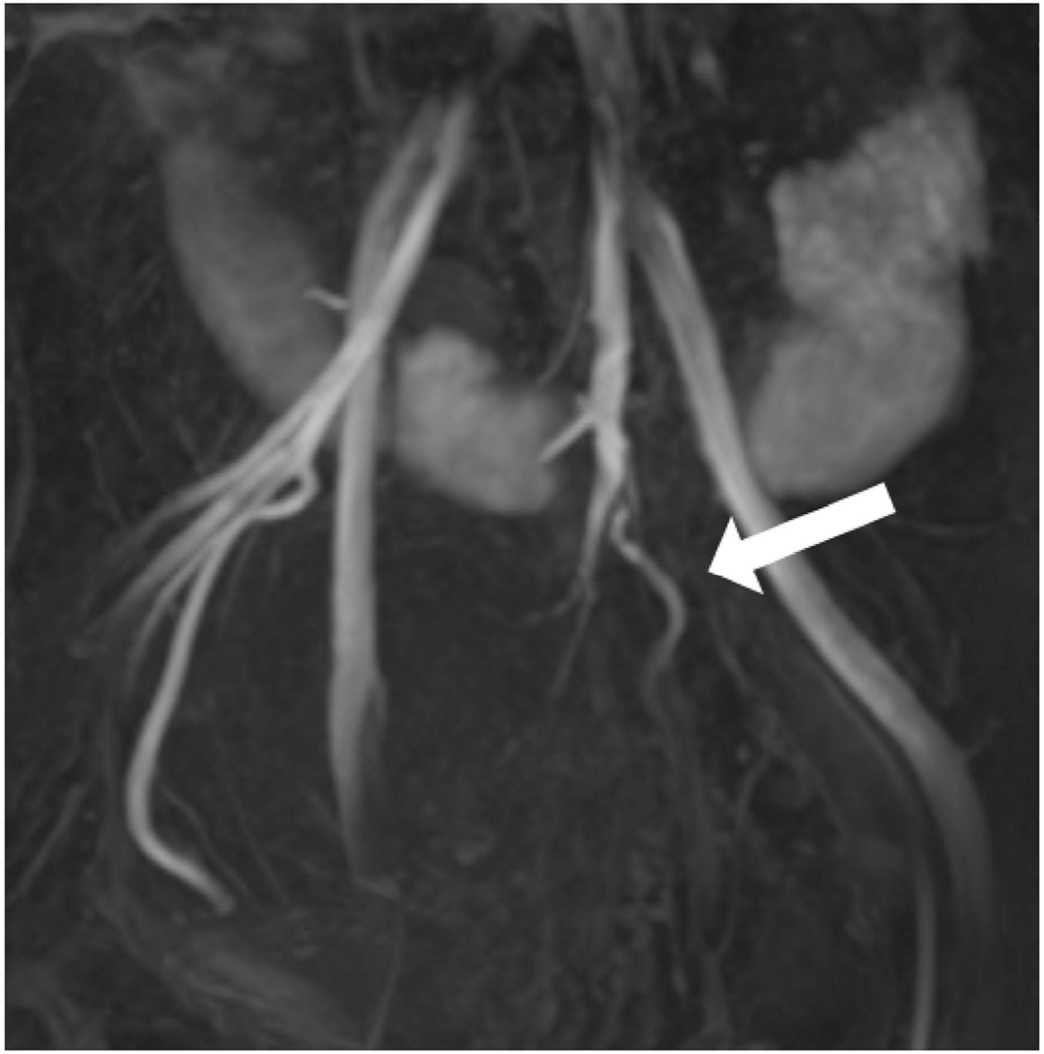

Figure 1B

Figure 2

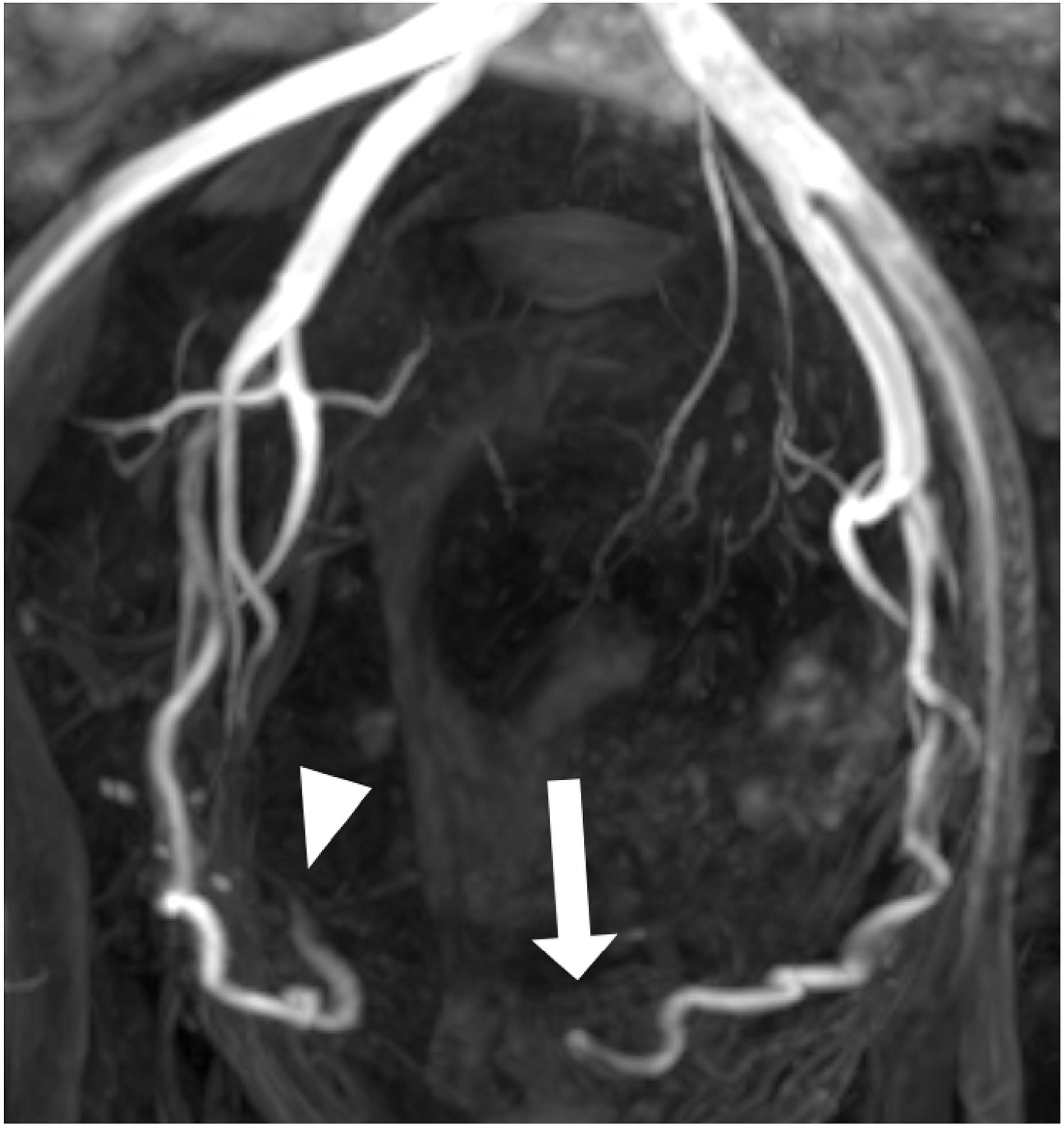

Figure 3

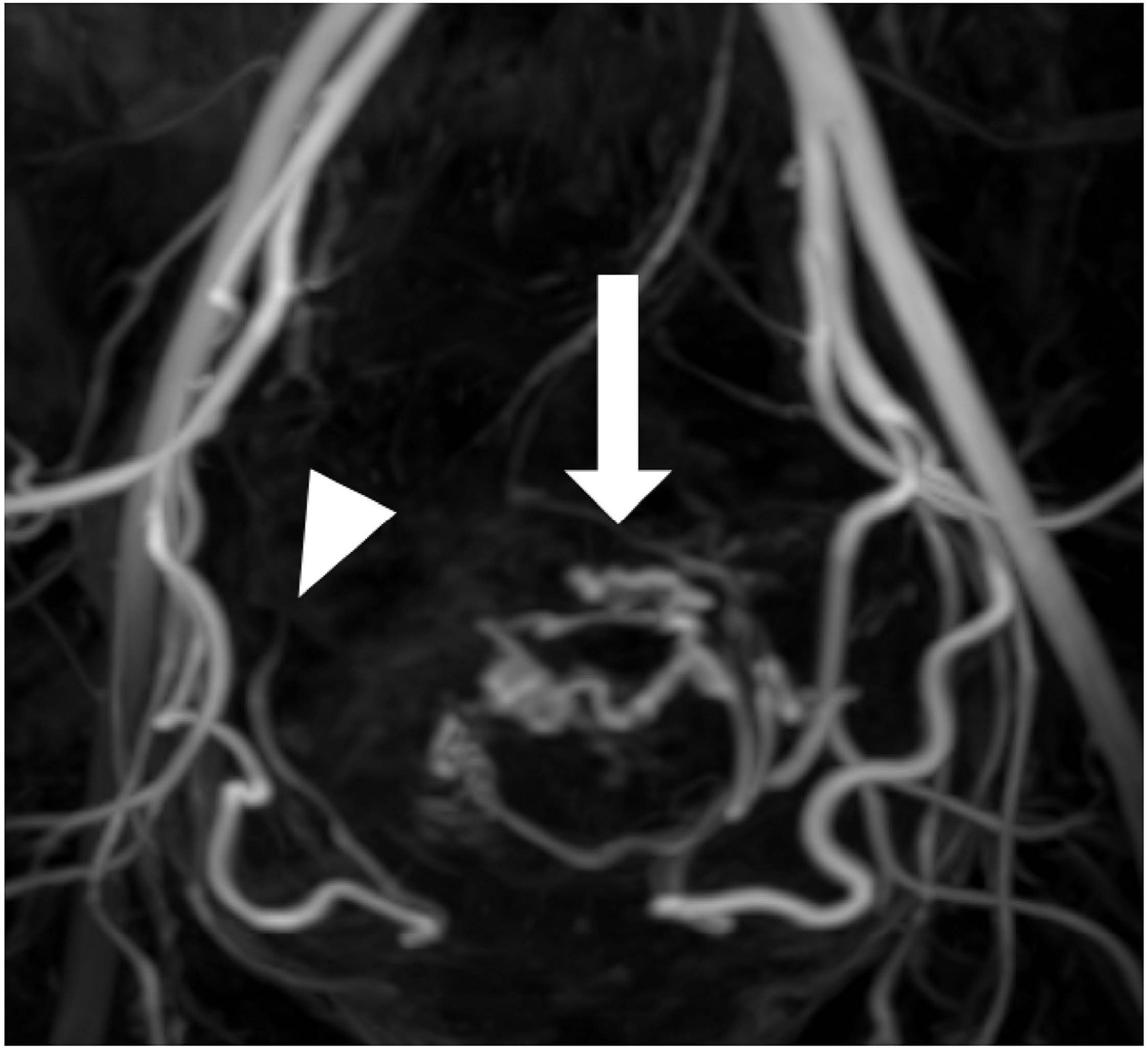

Figure 4

Figure 5

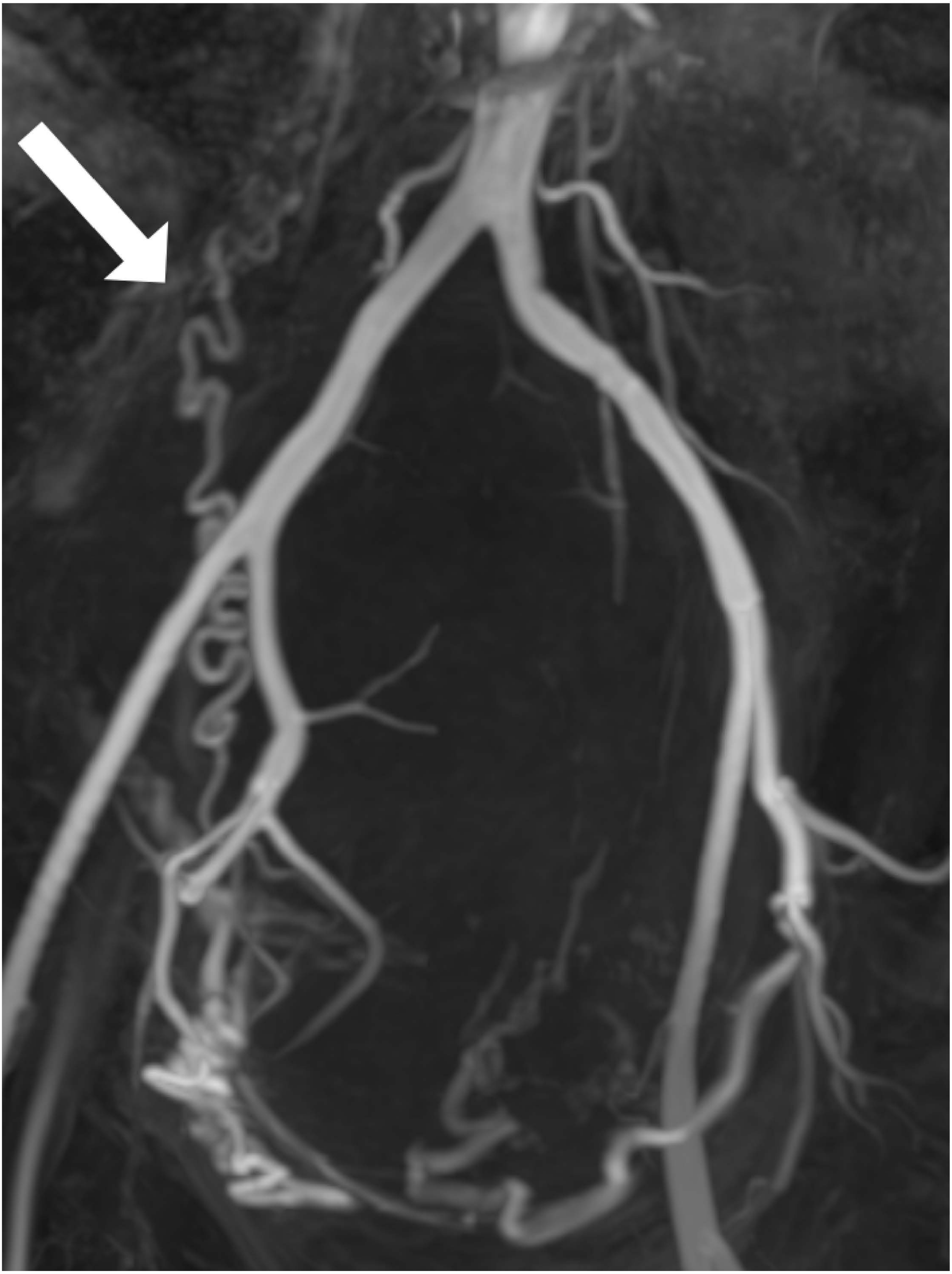

Figure 6