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Original Article

Diffusion-weighted MR imaging and Doppler ultrasonography in the evaluation of renal parenchyma in acute ureteral obstruction

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Abstract: Objective: To compare the efficacy of diffusion-weighted (DW) magnetic resonance (MR) imaging and Doppler ultrasonography (US) by using quantitative markers in acute unilateral obstruction due to renal stones. Methods: This prospective study included 28 patients with unilateral ureteral obstruction and 18 healthy control subjects. In Doppler US and DW MR imaging, resistive index (RI) and apparent diffusion coefficient (ADC) values were measured respectively. The results were compared in patients and in control subjects. Paired samples test, two-tailed unpaired Student's t test and Spearman analysis were performed for statistical analysis. Results: The mean RI in the 28 obstructed kidneys was significantly higher than the mean RI in unobstructed kidneys and in control subjects ($P < 0.05$). The ADC of obstructed kidneys in the cortex was significantly lower than the ADC of the contralateral unobstructed kidneys ($P < 0.05$). The ADC of unobstructed kidneys was significantly higher than the ADC of control subjects in the cortex ($P < 0.05$). RI and ADC values yielded no significant correlation. Conclusion: Doppler US and DW MR imaging provide accurate and noninvasive diagnosis, Doppler US may be preferred as it is a more practical technique compared to DW MR imaging in the evaluation of acute ureteral obstruction due to renal stones.

Keywords: Ureteral obstruction, magnetic resonance, diffusion weighted imaging, doppler ultrasonography, renal parenchyma

Introduction

Early, noninvasive and accurate diagnosis and relief of acute ureteral obstruction due to renal stones is important. As inadequate diagnosis and management may lead to functional and biochemical alterations in kidneys by decreasing the renal blood flow and glomerular filtration rate, untreated cases may ultimately result in irreversible renal damage [1, 2]. In daily practice the diagnosis of ureteral dilatation due to renal stones can easily be made with ultrasonography (US), intravenous pyelography or computed tomography (CT). However the ability of these modalities in demonstrating the obstruction in kidneys is limited. Since the determination of dilatation in renal collecting system and ureter does not always reflect the obstruction and also a non-dilated collecting system does not exclude the presence of an obstruction. Furthermore, intravenous pyelography and CT require additional contrast material injection to delineate the extent of obstruction and they are the sources of ionizing radiation. Therefore, doppler US and diffusion weighted (DW) magnetic resonance (MR) imaging may help in the diagnosis of obstruction due to renal stones in challenging cases by demonstrating the functional alterations in kidneys as noninvasive methods without contrast material administration or ionizing radiation. Intrarenal Doppler US has been shown to have the potential of identifying the acute renal obstruction by providing physiologic information on renal parenchyma [3, 4]. The arterial resistive index (RI) is the most widely referenced measurement in this manner, although there has been variety on its sensitivity and specificity in the reported series [3-7]. Diffusion-weighted (DW) magnetic resonance (MR) imaging is also a noninvasive imaging technique that provides quantified information on diffusion of water molecules within tissues. Apparent diffusion coefficient (ADC) maps provide quantitative analysis of DW imaging with measuring the degree of diffusion. When the diffusion of water molecules are restricted, ADC value decreases. DW MR imaging, is being used to yield functional data in renal diseases in recent years [8-12], although there is still limited reports on its use in acute renal obstruction [9, 13, 14]. The purpose of this study is to prospectively compare the efficacy of Doppler US and DW MR imaging by using quantitative markers in the determination of acute unilateral ureteral obstruction due to renal stones. To our knowledge, no studies combining Doppler US with DW MR imaging for this purpose have been reported previously.

Materials and methods

Patient population

This prospective study was approved by the institutional ethical board and written informed consent was obtained from all participants. Twenty-eight consecutive patients (six women, 22 men; mean age, 32.3 ± 6.7 years [standard deviation]; age range, 19-43) referred to our emergency department due to acute unilateral renal colic were studied between March 2013 and June 2013. In all patients, a unilateral ureteral calculus was diagnosed with US or unenhanced helical CT. The median time between the onset of symptoms and radiologic work-up was 26 hours (range, 11-72 hours). Initially Doppler US was performed followed by MR imaging on the same day before stone treatment. A control group of 18 healthy volunteers (five woman, 13 men; mean age, 29.2 ± 6.9 years; age range, 18-40 years), without a history of renal or systemic disease underwent the same Doppler US and MR imaging protocol.

All patients received a standard analgesic treatment protocol for renal colic including a nonsteroidal antiinflammatory drug (NSAID) (diclophenac sodium [Voltaren, 75 mg intramuscularly; Novartis Pharma, Stein AG, Switzerland]. In 12 patients NSAID treatment was combined with an opioid derivative (fentanyl citrate [Fentanyl 0.05 mg/ml, Janssen Pharmaceutica, Belgium]).

The patients with acute renal colic due to unilateral calculus diagnosed by US or unenhanced helical CT were included in the study. Exclusion criteria were previous renal stone treatment, current or chronic parenchymal or infectious renal disease, contraindication to MR imaging and an incomplete MR examination (i.e., image distortion or artifacts). Blood urea nitrogen (BUN) and serum creatinine values were obtained.

Doppler US techniques and image acquisition

Obstructed and contralateral unobstructed kidneys of the patients and healthy control subjects were examined prospectively by conventional gray-scale US and Doppler US. All US and Doppler US examinations were performed with high resolution US scanner (Aplio MX, Toshiba Medical Systems, Tokyo, Japan) with a multifrequency 2-5 MHz convex transducer. The kidneys were examined with the patient in deep inspiration and supine oblique position.

MR imaging techniques and image acquisition

All MR imaging examinations were performed in 1.5 Tesla MR scanner (Magnetom Avanto TIM, Siemens, Erlangen, Germany) with a 6 channel phased-array body matrix coil. MR examinations included the MR urography and DW MR images. The following imaging series were obtained for MR urography images: (1) coronal T2-weighted half-fourier rapid acquisition (HASTE); (2) coronal 3D T2-weighted respiratory triggered 'sampling perfection with application optimized contrasts using different flip angle evolution' (SPACE) sequence. Upon the completion of the above mentioned protocol, HASTE and SPACE images were converted by a maximum intensity projection (MIP) technique to the images that were similar to conventional urographic images. For functional evaluation, axial DW MR images (b = 0, and 150, 500, 900 sec/mm^2) were obtained. In addition, axial T1-weighted fast low angle shot (FLASH), in phase and oppose phase gradient-echo images and axial HASTE images were obtained to assess renal parenchyma. All patients and control subjects underwent the same imaging protocol. Imaging time was approximately 15 min. Detailed image acquisition protocols are given in the **Appendix**.

Doppler US image analysis

Doppler US images were prospectively reviewed by an experienced radiologist (FNSB, with 10 years of renal Doppler US imaging experience).

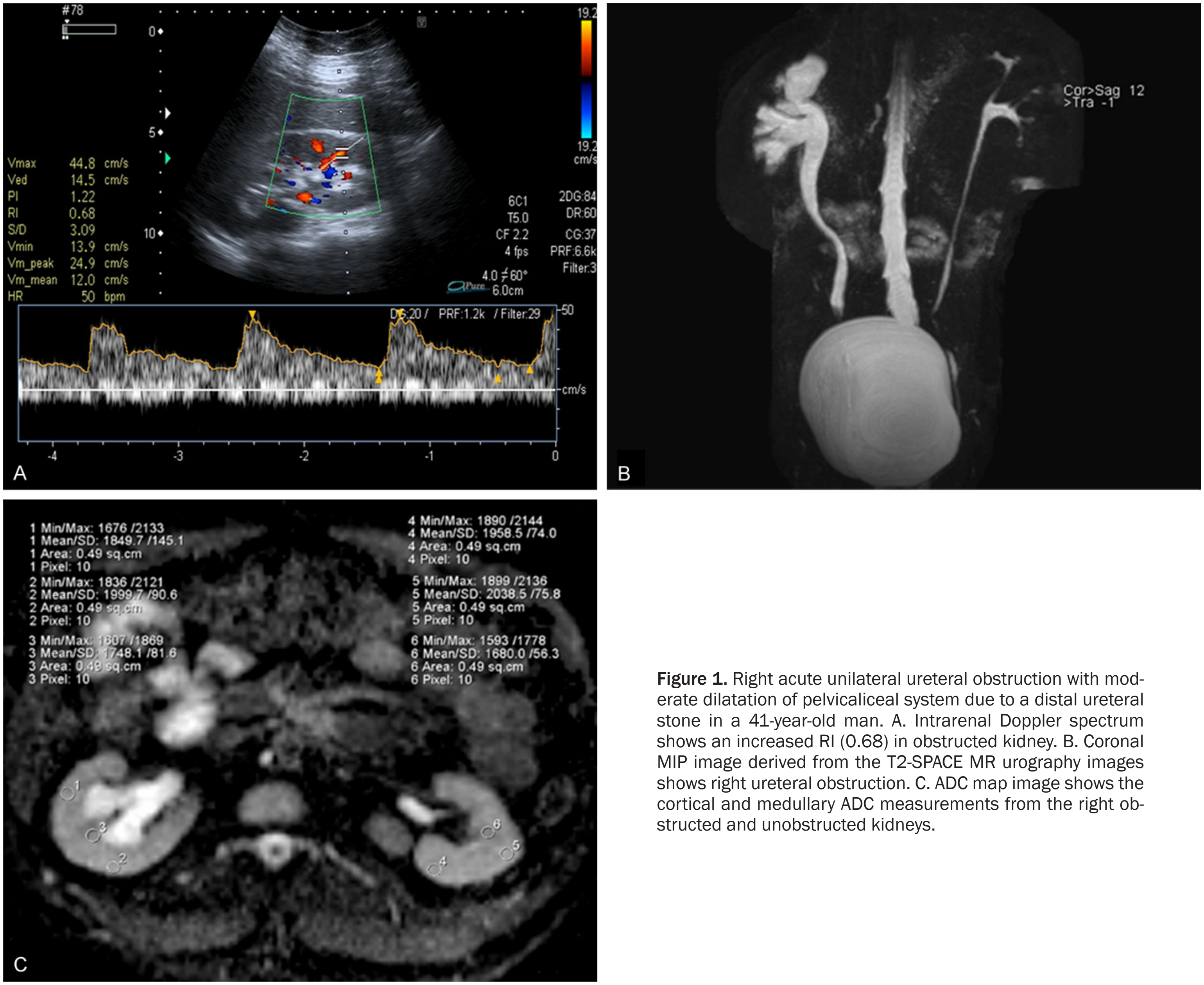

Figure 1. Right acute unilateral ureteral obstruction with moderate dilatation of pelvicaliceal system due to a distal ureteral stone in a 41-year-old man. A. Intrarenal Doppler spectrum shows an increased RI (0.68) in obstructed kidney. B. Coronal MIP image derived from the T2-SPACE MR urography images shows right ureteral obstruction. C. ADC map image shows the cortical and medullary ADC measurements from the right obstructed and unobstructed kidneys.

Table 1. Doppler US imaging: comparison of RIs

	RI mean ± SD	
	Obstructed	Unobstructed
Patients	0.64 ± 0.04	0.59 ± 0.03
*P value**		*0.001*
Control subjects	0.61 ± 0.02	
*P value***	*0.008*	*0.005*

*P** values for obstructed versus unobstructed kidneys, *Paired Samples Test, P < 0.05; P*** values for patients versus control subjects. *Student-t Test, P < 0.05.*

The radiologist was blinded to clinical findings except for the knowledge that each patient had renal colic. The degree of pelvicalyceal dilatation was subjectively graded as absent, mild, moderate, or marked on grey-scale images. Renal stones were also noted. At least five Doppler spectra were obtained from more than three regions (upper, middle and lower portions). Doppler signals were obtained from arcuate arteries at the corticomedullary junctions and, or interlobar arteries along the border of the medullary pyramids (**Figure 1A**). The Doppler waveforms were made using the optimal pulse repetition frequency, the lowest possible wall filter and appropriate Doppler sample width. The renal RI was calculated as: (peak systolic velocity-end diastolic velocity)/peak systolic velocity.

MR image analysis

MR images were reviewed by the same radiologist (Radiologist FNSB, 9 years of renal MR imaging experience) one week after Doppler US in random order. The radiologist was blinded to clinical and Doppler US findings of the patients. Presence of pelvicaliceal dilatation (absent, mild, moderate, or marked) and ureteral obstruction were noted (**Figure 1B**).

ADC maps were generated from DW MR images automatically by the MR scanner and the DW MR data were transferred to an independent workstation (Leonardo console, software version 2.0; Siemens AG Medical Solutions, Forchheim, Germany). Three circular regions of interest (ROIs) were placed for upper pole, midpole, and lower pole of the cortex and medulla on several sections covering entire kidney (number of ROIs: 9 for cortex and 9 for medulla; mean ROI size: 0.48 cm^3 ± 0.02 for cortex and 0.47 cm^3 ± 0.02 for medulla, **Figure 1C**). The average ADC within each ROI was then calculated. ADC values are expressed in square millimeters per second.

Statistical analysis

Statistical calculations were performed on Number Cruncher Statistical System 2007&-Power Analysis and Sample Size 2008, Statistical Software (Utah, USA). Statistical analysis was performed by using Paired Samples Test for the comparison of the RI and ADC values in obstructed and contralateral unobstructed kidneys in patients. Two-tailed unpaired Student's t test was used when comparing the obstructed and unobstructed patients with volunteers. The RI values were correlated with ADC values in the obstructed, unobstructed and control kidneys by using Spearman correlation analysis. For all statistical tests, a *p* value of less than 0.05 was considered to indicate a statistically significant difference.

Results

Clinical and laboratory findings

The US, non-enhanced helical CT and MR urography examinations identified 16 patients had stones in the distal ureter and remaining 12 had stones in the proximal ureter. Nineteen of the patients had ureteral stones in the right side, and 9 had stones in the left side. Nine of the patients had mild, 6 had moderate and remaining 13 of them had marked pelvicalyceal dilatation due to the stones. The contralateral ureter was normal in all patients. Two patients also had stones in the ipsilateral kidney and one had stones in both kidneys. The median blood urea nitrogen (BUN) level was 13.03 mg/dL (range 4.3-22.2 mg/dL) and creatinine level was 0.86 mg/dL (range 0.52-1.7).

Doppler US findings

Table 1 summarizes the RI values and the difference between obtructed, contralateral unobstructed and control kidneys. The mean RI in the 28 obstructed kidneys (0.64 ± 0.04) was significantly higher than the mean RI in 28 unobstructed kidneys (0.59 ± 0.03, *P*: 0. 001) and the mean RI in 36 control kidneys (0.61 ± 0.02, *P*: 0.008).

DW MR imaging findings

Table 2 summarizes the ADC values in obstructed, contralateral unobstructed and control kidneys. The ADC of obstructed kidneys in the cortex ($190 \pm 9 \times 10^{-5}$ mm^2/sec) was significantly lower than the ADC of the unobstructed kidneys ($197 \pm 8 \times 10^{-5}$ mm^2/sec, (*P:* 0.01). The ADC measurement yielded no significant difference in the medulla. Similarly, there was no significant difference between obstructed kidneys and control subjects regarding cortex and medulla. The comparison of the ADC between unobstructed kidneys and control subjects showed a statistically significant increase in the cortex of unobstructed kidneys ($197 \pm 8 \times 10^{-5}$ mm^2/sec for unobstructed kidneys and $187 \pm 9 \times 10^{-5}$ mm^2/sec for control subjects, *P*: 0.001) and a slight nonsignificant increase in the medulla.

Discussion

The results of our study showed that the mean RI of obstructed kidneys was significantly higher than the mean RI of unobstructed kidneys and of control subjects. Doppler US provides physiologic data of the renal parenchyma regarding the evaluation of intrarenal arterial resistance [3]. RI, as the main quantitative indicator of intrarenal arterial resistance, has been shown to have variable values (0.62-0.73) in different series investigating renal parenchyma in acute unilateral obstruction [4, 15-17]. It has been stated that this may be caused by a number of influences such as the degree and the duration of obstruction, age, hypotension, decreased heart rate and other nephropathies [3, 17-21]. Despite the variations in the reported RI values in acute renal obstruction, kidneys with acute obstruction showed significant increase in RI compared with unobstructed kidneys and/or control group [4, 15-17]. Our results are consistent with the literature suggesting that RI is a valuable parameter in the evaluation of acute renal obstruction showing significantly higher values in obstructed kidneys compared with unobstructed kidneys and control subjects respectively. The significantly higher RI values in obstructed kidneys may be explained by the increase in intrarenal arterial resistance during acute obstruction.

The current study also showed that ADC was significantly lower in the cortex of obstructed kidneys compared with unobstructed kidneys ($P < 0.05$). In the medulla no significant difference was detected in ADC between the groups. There has been studies searching the role of DW MR imaging in the evaluation of renal functions in different parenchymal diseases [14, 22-24]. However, the studies yielding DW MR imaging in acute unilateral renal obstruction are still limited. Thoeny et al. performed DW MR imaging calculating the diffusion and perfusion contributions to the total ADC value by the acquisition of multiple *b* values in patients with acute unilateral ureteral obstruction [9]. Since we applied only four diffusion gradients, our ADC value were considered to reflect a combination of both diffusion and perfusion contributions so it may be comparable with their total ADC value. Although the investigators stated that no significant differences were observed between the total ADC of the cortex or medulla of the obstructed and unobstructed kidneys, ADC in the cortex was still slightly decreased in the obstructed kidneys. However, in our study, the decrease in ADC value in the cortex were statistically significant in obstructed kidneys compared to unobstructed group. It is known that the restriction of free movement of water molecules in both the extracellular and intracellular space leads to a decrease in ADC value. The increased hydrostatic pressure in glomeruli may lead to decreased ADC value in the obstructed kidneys. The lower ADC measurements in the cortex may be used as a quantitative marker in acutely obstructed kidneys indicating a functional alteration.

In our study, no significant correlation was found between RI and ADC values for all three groups. However, when RI and ADC values in obstructed and unobstructed kidneys were compared separarately, a significant increase in RI and a significant decrease in ADC value in the cortex of the obstructed kidneys were found. In addition, when unobstructed and control kidneys were compared regarding RI and ADC values, a significant difference was found. The RI was significantly lower in unobstructed kidneys compared to normal subjects while the ADC was significantly higher in unobstructed kidneys compared to normal kidneys. This may be attributed to compensatory mechanisms in contralateral kidneys increasing renal functions by decreasing intraarterial resistance or medication effects caused by NSAIDs received only by the patient group. NSAIDs which inhibit pros-

Table 2. DW MR imaging: comparison of ADCs

	ADC ($\times 10^{-5}$ mm^2/sec) mean ± SD			
	Cortex		Medulla	
	Obstructed	Unobstructed	Obstructed	Unobstructed
Patients	190 ± 9	197 ± 8	172 ± 8	172 ± 1
*P value**		*0.014*		*0.767*
Control subjects	187 ± 9		169 ± 9	
*P value***	*0.172*	*0.001*	*0.266*	*0.212*

*P** values for obstructed versus unobstructed kidneys, *Paired Samples Test, P < 0.05; P*** values for patients versus control subjects. *Student-t Test, P < 0.05.*

toglandin synthesis can cause this effect by decreasing intracapillary pressure [9]. The compensatory and pharmaceutical effects on renal RI and ADC in contralateral kidneys merit futher investigation. Regarding obstructed kidneys a significant difference was detected compared to control kidneys in only RI values which were significantly higher in obstructed kidneys.

Our study has several limitations: (1) The presence of ureteral dilatation was only evaluated by non-contrast MR urography. Additional contrast-enhanced MR urograhy or intravenous urography were not performed due to the limited time, risk of contrast reaction and nephrotoxicity. In addition, these procedures were relatively invasive with additional radiation exposure in IVP. Scintigraphy was not performed due to the similar reasons. (2) There was a relative small number of patients. (3) A comparison of the quantitative measurements between before and after treatment was not made as the measurements of the control group were already obtained. We thought that posttreatment measurements could be replaced by control values. However the evaluation of the posttreatment results might ultimately determine the value of these methods in the diagnosis of ureteral obstruction. (4) The pharmaceutical effects could not be excluded since all patients received medication before the examinations. (5) We did not separate the diffusion and perfusion contributions to ADC values since it needs the application of several diffusion gradients which is not employed in our MR scanner.

In practice Doppler US is a reliable and feasible technique for the diagnostic evaluation of acute unilateral ureteral obstruction. However, it is user dependent and the quantitative measurements may not be standardized. Besides, the utilization of an appropriate technique and the cooperation of the patients are essential for obtaining accurate results. MR imaging on the other hand, is an uncomfortable process for the patients with renal colic and the method is not cost-effective compared to Doppler US. Furthermore, ADC measurement in renal parencyma is time consuming because it requires multiple ROI drawings. We think that Doppler US may be performed in renal colic patients requiring an urgent management during daily practice.

In conclusion, our results suggest that by using quantitative markers, both Doppler US and DW MR images may provide accurate and noninvasive diagnosis of acute unilateral obstruction due to renal stones. Doppler US may be preferred in the evaluation of acute ureteral obstruction as it is a more practical technique compared to DW MR imaging.

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Disclosure of conflict of interest

None.

Abbreviations

US, ultrasonography; CT, computed tomography; MR, magnetic resonance; DW, diffusion weighted; RI, resistive index; ADC, apparent diffusion coefficient; NSAID, nonsteroidal antiinflammatory drug; HASTE, half-fourier rapid acquisition; SPACE, sampling perfection with application optimized contrasts using different flip angle evolution; MIP, maximum intensity projection; BUN, blood urea nitrogen.

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Appendix

Siemens MR scanner protocol

An effective sensitivity encoding (GRAPPA, parallel imaging) factor of two was used in all sequences. The coronal T2-weighted HASTE imaging parameters were as follows: axial resolution, 1.7 × 1.4 mm; section thickness, 4 mm; intersection gap, 0.9 mm; repetition time msec/echo time msec, 11.9/95; flip angle, 90°; matrix, 256 × 256; field of view, 30-35 cm; bandwidth, 440 Hz per pixel, number of signals acquired, one. The coronal 3D T2-weighted SPACE imaging parameters were as follows: axial resolution, 1.4 × 1.3 mm; section thickness, 1.5 mm; repetition time msec/echo time msec, 1620/697; flip angle, 140°, turbo factor of 14, matrix, 320 × 320; field of view, 30-35 cm; bandwidth, 372 Hz per pixel, number of signals acquired, 1.5.

The axial DW MR imaging parameters were as follows: axial resolution, 2.2 × 2.2 mm; section thickness, 5 mm; intersection gap, 0 mm; repetition time msec/echo time msec; 4000-4700/80-90 ms; flip angle, 55°; matrix, 256 × 256; field of view, 30-35 cm; bandwidth, 1634 Hz per pixel, number of signals acquired, six. The axial T1-weighted fast low angle shot in phase and oppose phase gradient-echo imaging parameters were as follows: axial resolution, 1.7 × 1.3 mm; section thickness, 4 mm; intersection gap, 1.0 mm; repetition time msec/echo time msec; 165/2.26 (TE1), 4.92 (TE2); flip angle, 70°; matrix, 256 × 256; field of view, 30-35 cm; bandwidth, 400 Hz per pixel, number of signals acquired, one. The axial T2-weighted HASTE imaging parameters were as follows: axial resolution, 1.5 × 1.3 mm; section thickness, 4 mm; repetition time msec/echo time msec, 1000/88; flip angle, 136°; matrix, 256 × 256; field of view, 30-35 cm; bandwidth, 501 Hz per pixel, number of signals acquired, one.