
Instrumentation, Technical Requirements: MRI

Yuji Watanabe

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Abstract

This section of the chapter provides practical guide for MR examination of the scrotum and comprehensive description of clinical applications. The techniques used for scrotal MR imaging can be implemented with virtually any MR unit. Several technical points are described in obtaining high-resolution scrotal MR imaging: patient preparation, coil selection, respiratory compensation, imaging planes, pulse sequence design, fat suppression, multiple contrast, injection of contrast material, and the scanning order of pulse sequences. Image analysis is also described in the evaluation of testicular volume and perfusion. The scrotal MR imaging can be clinically applied for acute scrotal symptoms, intrascrotal masses, scrotal trauma, nonpalpable testis, infertility, etc. The recommended protocol of pulse sequences should include T1-weighted, FS-T2-weighted, and heavily T2-weighted imaging in the coronal plane. Some changes to the basic protocol should be made depending on the clinical settings. The dynamic subtraction contrast-enhanced MR imaging can be used to provide information about testicular perfusion with the use of dynamic subtraction contrast-enhanced technique.

1 Introduction

Magnetic resonance (MR) imaging has been thought to play a minor and questionable role in the evaluation of scrotal symptoms (Hricak et al. 1995;

Y. Watanabe (✉)
Department of Radiology, Kurashiki Central Hospital,
1-1-1-Miwa, Kurashiki 710-8602, Japan
e-mail: yw5904@kchnet.or.jp

Trambert et al. 1990). Clinical application has been limited to a clinical setting when ultrasonography proves to be inadequate or inconclusive. However, with the use of dynamic subtraction contrast-enhanced technique, MR imaging can provide information about testicular perfusion due to its high sensitivity for contrast enhancement (Baker et al. 1987; Cheng et al. 1997; Costabile et al. 1993; Kodama et al. 2000; Landa et al. 1988; Watanabe et al. 2000).

When compared with the normal-side testis, torsion, infarction, and hemorrhagic necrosis of affected-side testis showed significant reductions in contrast enhancement, whereas tumors and orchitis showed significant increases (Watanabe et al. 2000). These findings lead MR imaging to a practical tool that relies on functional as well as anatomic assessments for improving diagnostic accuracy.

2 Static Magnetic Field Strength

The techniques used for the scrotal MR imaging (Watanabe et al. 2000) can be implemented with virtually any MR unit (Choyke 2000). There is no significant difference in the interpretation and quantification of scrotal images among scrotal imaging with any static magnetic field strength. Image quality and signal-to-noise ratio can be better with high-field-strength MR unit. However, imaging criteria at 1.5 T for image interpretation are applicable at other field strength 0.5, 1.0, and 3.0 T, etc. In contrast, the problem will be a susceptibility artifact, which causes signal loss or image distortion at the air–tissue interface especially found at high field strength such as 3.0 T. To minimize such a problem, it is recommended to use turbo spin echo pulse sequence, which can be less influenced by susceptibility artifact than gradient echo sequence.

The problem might be heating of the scrotum by high-magnetic-field-strength MR imaging which could affect spermatogenesis adversely. However, it was reported that the temperature recorded, when MR imaging with 1.5 T at relatively high specific absorption rates, produced a significant increase in scrotal skin temperature, which was below the threshold known to affect spermatogenesis in mammals (Shellock et al. 1990).

3 MR Imaging

Both T1- and T2-weighted turbo (fast) spin-echo sequences are essential for scrotal MR imaging. Contrast-enhancement and special techniques, such as dynamic subtraction contrast-enhanced MR imaging, can also be used in cases where further tissue characterization is needed or when patients present with acute scrotal pain. There are several points to be considered in obtaining high-resolution scrotal MR imaging: coil selection, respiratory compensation, imaging planes, pulse sequence design, multiple contrast, contrast enhancement, and fat suppression.

3.1 Coil Selection

A circular surface coil is recommended for best results in imaging the testis (Rholl et al. 1987). In the choice of a surface coil, patient age, size of scrotum and imaging coverage should be taken into consideration. A circular 17 cm coil is usually used for adolescents and adults. A small circular coil of 11 or 8 cm is used for children and adolescents. A circular surface coil is recommended to be placed on a patient's lower pelvis and centered over the scrotum (Fig. 1).

3.2 Respiratory Compensation

Respiratory compensation may be used to reduce motion artifact. However, it takes a long scan time to obtain MR images with respiratory compensation. In patients with acute scrotal symptoms, it is required to shorten the imaging time as much as possible and not to use respiratory compensation. Image quality obtained without respiratory compensation can be high enough for the diagnosis (Frush and Sheldon 1998).

3.3 Preparation for Patients

Adequate support and positioning of the scrotum under the surface coil are key factors in obtaining diagnostic-quality MR images. Especially, the bilateral testes should be arranged to maintain nearly equal distance from the surface coil (Rholl et al. 1987; Baker et al. 1987).



Fig. 1 Surface coil. A variety of circular surface coils: 17, 11 and 8 cm in diameter

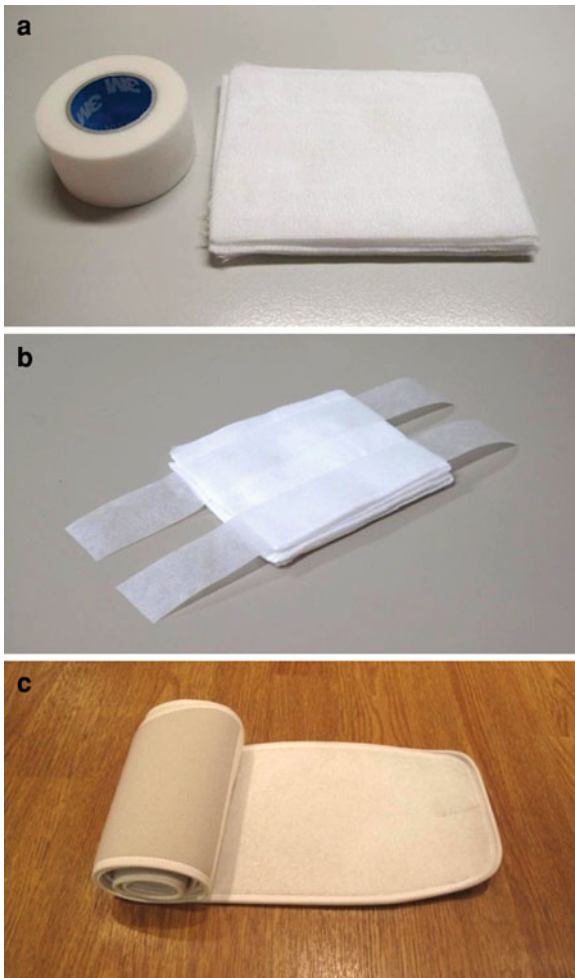


Fig. 2 Stuff required for preparations. **a** Adhesive tape and towel. **b** Gauze. **c** Band with velcro tape

Before examination, stuffs such as adhesive tape, gauze, towel, and bands should be prepared for patients (Fig. 2). In practice, with the patient in the

supine and feet-first position on the patient table, the penis is kept upward, covered with a light cloth such as gauze, and then taped against the abdominal wall (Fig. 3a). Towels or sponges are placed between the thighs to minimize motion artifact. The scrotum are then lifted up gently and fixed on the thighs. Then, bands are used to get the thighs as close as possible to keep the scrotum on the thighs. The surface coil is placed over the scrotum in a flat position, supported, and secured (Fig. 3b). To use parallel imaging technique, another surface coil could be placed under the bottom (van den Brink et al. 2003).

A peripheral intravenous line with a 21-gauge needle is placed into the subcutaneous veins of the forearm or antecubital fossa. Then, the patient should be brought into the bore of MR unit with the feet first (Fig. 3c).

The special attention should be paid to infant patients who require sedation in MR imaging. Infant patients are laid on the patient table gently and the surface coil is placed on the scrotum. No other preparations for the scrotum are necessary.

3.4 Imaging Plane and Coverage

The testes are usually examined in at least two planes, along the length and transverse axes (Fig. 4). Thus, the coronal and transaxial plane images are recommended to allow direct comparison of the two testes and evaluation of the spermatic cord. The coronal plane is ideal for imaging the scrotal contents, allowing complete visualization of all the important anatomic structures (Baker et al. 1987). The size and signal intensity of each testis and the epididymis are compared with those on the opposite side.

Optimal coverage of the scrotum is provided by thin sections (4–5 mm) with a 0.4–0.5 mm intersection gap and a 8–22 cm field of view (Table 1).

3.5 Pulse Sequence Design and Multiple Contrast

As shown in Table 1, there are a variety of pulse sequences and parameters used for scrotal imaging. Common pulse sequences used are turbo (fast) spin echo (TSE) (Hricak et al. 1995; Rholl et al. 1987; Baker et al. 1987). The advantages of this TSE sequence

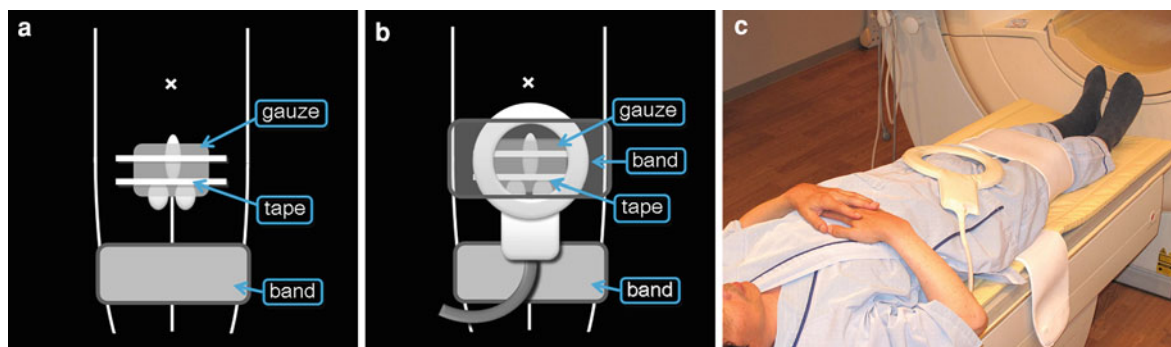


Fig. 3 Preparation for patients. **a** Taping penis on the abdominal wall. **b** Placement of a surface coil on the scrotum. **c** Photograph of a patient going into the bore with the feet first

are (a) multiple contrast weightings such as T1- and T2-weighted imaging, (b) high-spatial resolution, (c) high signal-to-noise ratio with use of a surface coil.

Lengthy examination time may decrease patient comfort and acceptability, and increase patient movement, which can lead to degradation of image quality from motion artifact. To reduce scan time by accelerating image acquisition, parallel imaging techniques such as sensitivity encoding, simultaneous acquisition of spatial harmonics can be applied with another surface coil placed under the bottom (van den Brink et al. 2003).

T1-weighted imaging provides anatomical information of testis, epididymis, and spermatic cord, which show intermediate signal intensity areas delineated by high signal intensity area of surrounding fat tissue (Hricak et al. 1995).

T2-weighted imaging shows a variety of tissue contrast depending on the echo time (TE) (Watanabe et al. 2000, 2007). T2-weighted images obtained with TE of 100 ms yield standard T2-contrast between testes, epididymis, spermatic cord, and surrounding fat tissue. With chemical-selective fat suppression, testes show homogeneous high signal intensity area (Watanabe et al. 2000, 2007; Frush and Sheldon 1998). Spermatic cord and epididymis demonstrates very high and intermediate signal intensity area, respectively. Long TE such as 350 ms produces heavily T2-weighted images which clearly demonstrate intravaginal fluid collection as very high signal intensity area and depicts testes and epididymis as intermediate signal intensities.

T2*-weighted gradient echo sequence should be incorporated in MR imaging of patients suspected of having testicular torsion (Watanabe et al. 2007). This

image is sensitive to susceptibility and important in the detection and characterization of lesions with short T2, such as acute hemorrhage (Bradley 1993; Hermier and Nighoghossian 2004).

Diffusion-weighted imaging of the scrotum may provide another information of testes about tissue characterization such as interstitial edema, capillary congestion, ischemic change, and degenerative change. Apparent diffusion coefficient (ADC) maps based on the diffusion-weighted images was reported to be useful for the early detection of testicular torsion in a rat model (Kaipia et al. 2005; Kangasniemi et al. 2001). Though diffusion-weighted imaging of the scrotum is still at a stage of investigation, it may be used for the detection of testicular torsion without contrast materials and for the evaluation of testicular dystrophy and degeneration in undescended testes and infertility.

Contrast-enhanced MR imaging gives additional information in scrotal disorders and facilitates diagnosis. It is helpful when findings at physical examination and ultrasound differ and when plain T1- and T2-weighted images are equivocal (Muller-Leisse et al. 1994). Especially, dynamic contrast-enhanced imaging with bolus infusion of contrast material provides important information about testicular perfusion (Watanabe et al. 2000, 2007).

3.6 Dynamic Subtraction Contrast-Enhanced MR Imaging

Contrast enhancement with special techniques called dynamic subtraction contrast-enhanced MR imaging contribute to the evaluation of testicular perfusion and further tissue characterization (Watanabe et al. 2000,

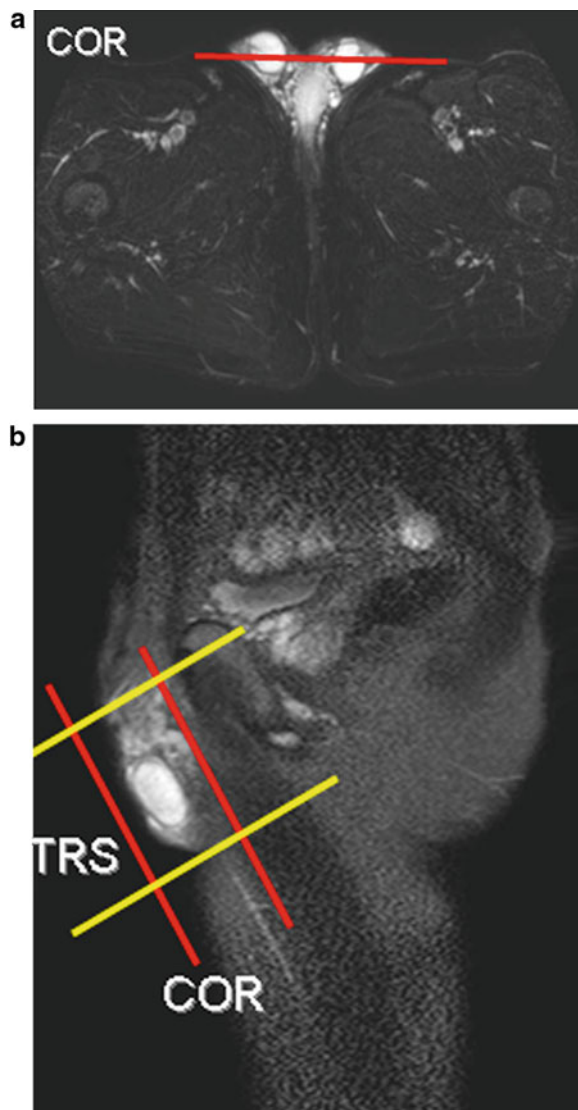


Fig. 4 Imaging planes. **a** Coronal imaging plane depicted on the transaxial image. **b** Coronal and transaxial imaging planes depicted on the sagittal image

2007). This technique can be implemented with virtually any MR unit. This method is simple, straightforward, and time efficient. Serial imaging is performed after a bolus injection of gadolinium-based paramagnetic contrast agents. Based on contrast enhancement of testis, testicular blood flow can be accurately assessed. The analysis of the enhancement profiles is simple enough to compare peak and up-slope of enhancement between normal and affected testis. This MR technique should be useful in distinguishing tumors from nonmalignant lesions and in

distinguishing torsion and trauma from other acute causes of pain (Choyke 2000).

In practice, the dynamic subtraction contrast-enhanced MR imaging is performed in the coronal plane. Fat-suppressed turbo spin echo sequence is recommended to obtain sufficient contrast enhancement of testis. Other scan parameters to achieve high image quality and appropriate temporal resolution of the scrotum are two signal acquisition, low–high k-space trajectory, 5–6 mm section thickness, 0.5–0.6 mm intersection gap, six slices, 180 mm field of view, 204×256 matrix, 50–60 s per sequence. Images are obtained before and after a rapid intravenous bolus injection of 0.1 mmol/kg of gadolinium-based paramagnetic contrast agents. The rapid injection of contrast agents is performed within 5 s, followed by flush of 20 ml physiological saline. Five imaging sets are consecutively acquired 15 s after the injection of contrast agents. First four imaging sets are obtained at no interval, except for that the last imaging set is obtained at an interval of 90 s after the end of the fourth imaging set. The actual examination time is approximately 6 min.

Then, the slice-by-slice subtraction is performed to obtain dynamic subtraction contrast-enhanced images. The data set obtained immediately before administration of contrast agents is used as a mask and subtracted from each of the five original data sets acquired after administration of contrast agents with commercially available software (Fig. 5).

3.7 The Scanning Order of Pulse Sequences

In general, non-contrast-enhanced images, such as T1- and T2-weighted images, should be first obtained, and then, contrast-enhanced images including dynamic subtraction contrast-enhanced imaging are subsequently obtained, if necessary. However, in patients with acute scrotal pain suspicious of testicular torsion, dynamic subtraction contrast-enhanced imaging can be first performed to provide information about testicular perfusion, which allows for accurate diagnosis of testicular torsion and prompt determination of treatment plan. Soon after knowing the results of testicular perfusion, fat-suppressed T2-weighted, heavily-T2-weighted and T2*-weighted images can be obtained. Though there may be minimal influence of administered contrast material on

Table 1 Scrotal imaging: pulse sequence parameters

Scan number	1	2	3	3'	4	5	5'	6	6'	7	8	8'
image contrast	Scout	T1WI	T2WI	T2WI	T2*WI	Heavily-T2WI	Heavily-T2WI	DWI	DWI	Dynamic subtraction CE	CE T1WI	CE T1WI
pulse sequence	TurboSE	TurboSE	TurboSE	TurboSE	FFE	TurboSE	TurboSE	SE-EPI	SE-EPI	TurboSE	TurboSE	TurboSE
imaging direction	three directions	coronal	coronal	transaxial	coronal	coronal	transaxial	coronal	transaxial	coronal	coronal	transaxial
TR	192 ms	500 ms	3606 ms	3568 ms	522 ms	5000 ms	5593 ms	1982 ms	1764 ms	466 ms	500 ms	500 ms
TE	16 ms	15 ms	100 ms	100 ms	20 ms	350 ms	350 ms	64 ms	61 ms	14 ms	15 ms	15 ms
Flip angle (degree)	90	90	90	90	25	90	90	90	90	90	90	90
Echo train length	3	3	9	9		65	65	single-shot	single-shot	3	3	3
Field of view	300 mm	220 mm	220 mm	220 mm	220 mm	220 mm	220 mm	280 mm	280 mm	180 mm	220 mm	220 mm
Matrix	192	204 × 256r	192 × 256r	192 × 256r	204 × 256r	256 × 256r	256 × 256r	128 × 256r	128 × 256r	204 × 256r	204 × 256r	204 × 256r
Section thickness	10 mm	4 mm	4 mm	4 mm	4 mm	4 mm	4 mm	5 mm	5 mm	6 mm	4 mm	4 mm
Intersection gap	5 mm	0.4 mm	0.4 mm	0.4 mm	0.4 mm	0.4 mm	0.4 mm	0.5 mm	0.5 mm	0.6 mm	0.4 mm	0.4 mm
Number of sections	3 each	16	16	16	16	16	16	15	15	6	16	16
Breathing	rest	rest	rest	rest	rest	rest	rest	rest	rest	rest	rest	rest
Band width (Hz/pixel)	107.2	210	71.5	71.5	217.1	183.4	214	21.4	37.9	145.8	210	221
Fat suppression	–	–	SPIR	SPIR	–	–	–	SPIR	SPIR	SPIR	SPIR	SPIR
Number of signal acquisition	2	3	3	3	2	4	4	8	8	2	3	3
Acquisition time	35.6 s	2 min 4 s	2 min 20 s	2 min 19 s	2 min 8 s	2 min 30 s	2 min 59 s	1 min 53 s	1 min 41 s	52.2 s × 6	2 min 4 s	2 min 4 s
Phase direction		F-H	F-H	A-P	F-H	F-H	A-P	F-H	A-P	F-H	F-H	A-P
Other parameters								Half scan 0.61 b = 800	Half scan 0.61 b = 800 with SENSE			

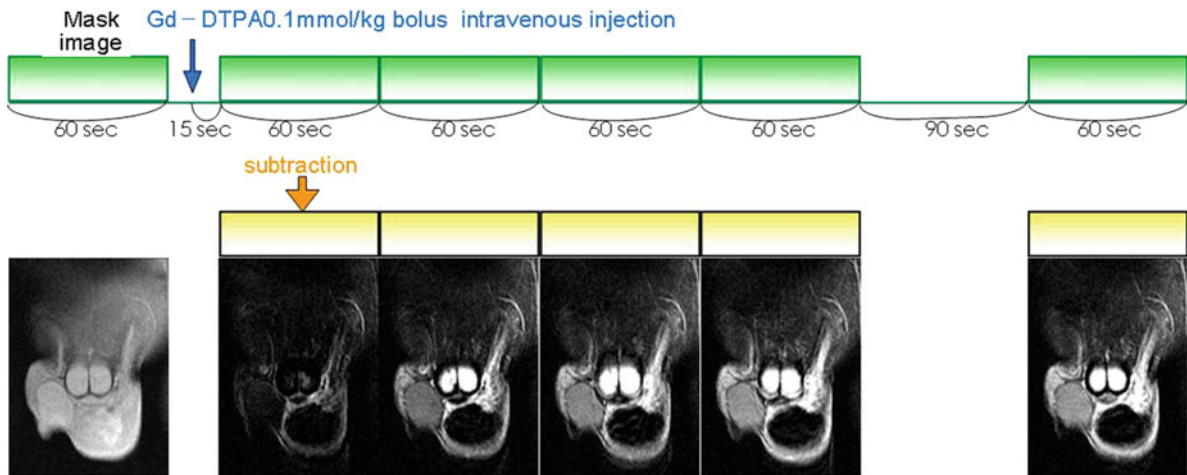


Fig. 5 Diagram and images of the dynamic subtraction contrast-enhanced imaging. The green and yellow belts demonstrate the data acquisition and post-processing using subtraction technique, respectively. In the set of serial MR images

obtained in a patient with testicular torsion, the twisted testis (left) shows no contrast enhancement and the normal testis (right) shows gradual increase in contrast enhancement

signal intensity, it is possible to evaluate the testicular damage such as hemorrhagic necrosis.

4 Image Analysis

4.1 Assessment of Contrast Enhancement

The dynamic subtraction contrast-enhanced images allow for visual assessment of testicular contrast enhancement (Fig. 5). The objective analysis of testicular enhancement can be performed with the contrast-enhancement profile curve as a function of time (Watanabe et al. 2000, 2007) (Fig. 6). Normal testes demonstrate slow and steady increase of contrast enhancement. Comparison of contrast enhancement between the right and left testes facilitate the evaluation of contrast enhancement of the affected-side testis with the unaffected-side testis serving as a normal control (Fig 6). The objective indexes used for the comparison are relative peak height(%) and relative mean slope(%) calculated from the contrast-enhancement profile curves as follows:

- Relative peak height (%) = maximum signal intensity of affected testis/that of unaffected testis $\times 100$
- Relative mean slope (%) = upslope of enhancement during the first 3 minutes of affected testis/that of unaffected testis $\times 100$

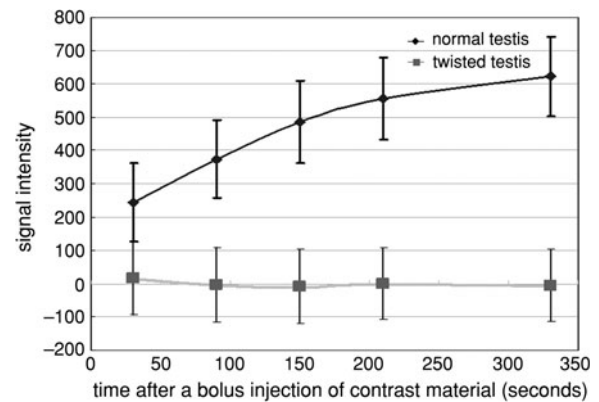


Fig. 6 Time-intensity profile curve. The time-intensity profile curve obtained in a patient with testicular torsion reveal no contrast enhancement for the twisted testis and steady progressive increase in contrast enhancement for the normal testis

The increase in tissue signal intensity after contrast material enhancement, depends on the blood supply and the volume of the extravascular fluid in the tissue (Newhouse and Murphy 1981; Young et al. 1980). Both the relative peak height and relative mean slope can be very helpful not only in distinguishing testicular diseases from extratesticular diseases but also in dividing testicular diseases into two groups: one group of diseases with no or decreased contrast enhancement including testicular torsion, testicular infarction, traumatic testicular hemorrhagic necrosis, and testicular

Table 2 Clinical applications and recommended protocol of pulse sequences

	Clinical setting	Recommended protocol: the scanning order ^a		
1	Acute scrotal symptoms	3-4-5-7	7-4-3-5	7
2	Intrascrotal masses	2-3-5-3'-7-8-8'		
3	Scrotal trauma	3-4-5-3'-7-8-8'		
4	Inguinal herniation	2-3		
5	Nonpalpable (undescended) testis	2-3-5-3'-7	2-3-5-3'	2-3-5-3'-6
6	Infertility	3-5-3'-5'-7	3-5-3'	3-5-3'-5'-6-6'
7	Hydrocele	3-5-3'-5'		

^a The numbers used are the scan number listed in Table 1

epidermoid cyst; and the other group of diseases with increased contrast enhancement including malignant testicular tumors and acute mumps orchitis (Watanabe et al. 2000; Terai et al. 2006).

4.2 Measurement of Testicular Volume

Testicular size can be determined with MR images by measuring the anteroposterior diameter on comparable transverse images of the left and right sides or by calculating testicular volume with the formula for an ellipsoid: $V = L \times W \times H \times 0.71$ (or 0.52), where V : volume, L : length, W : width, and H : height, as reported with ultrasound imaging (Oyen 2002; Paltiel et al. 2002). Although these measurements are not acquired routinely, they should be obtained in patients with varicocele, testicular atrophy, or acute scrotum to assess changes in testicular size. Testicular volume is approximately 1–2 cm³ before the age of 12 years and reaches 4 cm³ in pubertal males. In the peripubertal period, a difference of 3 mm in anteroposterior diameter is significant (Baud et al. 1998).

5 Clinical Applications and Protocol for Scrotal MR Imaging

The scanning protocol of pulse sequences recommended for the scrotal MR examinations should vary depending on the clinical settings. The basic protocol for the scrotal imaging should include T1-weighted, FS-T2-weighted, and heavily T2-weighted imaging in the coronal plane for a minimum requirement. Some changes to the basic protocol are necessary for the evaluation of the following pathology or clinical

symptoms (Table 2). The major clinical applications for MR imaging of the scrotum include the following.

1. *Acute scrotal symptoms suspicious of testicular torsion.* The recommended protocol should implement FS-T2-weighted, T2*-weighted, heavily T2-weighted and dynamic subtraction contrast-enhanced imaging in the coronal plane (Watanabe et al. 2000, 2007). Those pulse sequences are usually performed in the order of scan described above. Among these sequences, however, dynamic subtraction contrast-enhanced imaging can be first performed to promptly obtain information about testicular perfusion. When the contrast enhancement of the affected testis is found to be normal, possibilities of testicular torsion can be ruled out except for a case of spontaneous detorsion. Then, FS-T2-weighted imaging can be added to obtain anatomical and inside information of testis and surrounding testicular structures. When the affected testis shows no or little contrast enhancement, FS-T2-weighted, T2*-weighted, heavily T2-weighted images are required to obtain information about the presence or absence of hemorrhagic necrosis of testis and/or epididymis. T1-weighted imaging is not always necessary and can be skipped.
2. *Intrascrotal masses* with need for differentiation between intra- and extratesticular masses as well as between malignant and benign masses and for local staging of testicular cancer: the recommended protocol should implement T1-weighted, FS-T2-weighted, heavily T2-weighted and dynamic subtraction contrast-enhanced imaging in the coronal plane, and contrast-enhanced FS-T1-weighted imaging in both the transaxial and coronal planes (Watanabe et al. 2000; Kim et al. 2007). FS-T2-

weighted and T1-weighted imaging is useful in the assignment of the lesion to the testis, epididymis, or other scrotal structure. Dynamic subtraction contrast-enhanced images are helpful in differentiating between malignant and benign tumors by demonstrating tissue vascularity of tumor. Contrast-enhanced FS-T1-weighted image is necessary for the local staging of testicular cancer such as extracapsular extension.

3. *Scrotal trauma.* The recommended protocol should implement FS-T2-weighted, heavily T2-weighted, T2*-weighted and dynamic subtraction contrast-enhanced imaging in the coronal plane, and contrast-enhanced FS-T1-weighted imaging in both the transaxial and coronal planes. Presence or absence of a hematocele and testicular rupture should be determined with MR imaging (Kim et al. 2007). T2*-weighted and dynamic subtraction contrast-enhanced images are important for demonstrating intra- or extra-testicular hematoma. Contrast-enhanced FS-T1-weighted image is also useful in the detection of capsular disruption.
4. *Inguinal and scrotal mass suspicious of inguinoscrotal herniation.* The recommended protocol should implement T1-weighted, FS-T2-weighted imaging in the coronal plane. T1-weighted image is very important to demonstrate fat tissue protruding through the inguinal canal (Shadbolt et al. 2001).
5. *Nonpalpable testis in the scrotum.* The recommended protocol should implement T1-weighted, FS-T2-weighted, and dynamic subtraction contrast-enhanced imaging in the coronal plane. Localization of the undescended testis can be done with T1-weighted and FS-T2-weighted images (Frush and Sheldon 1998; Shadbolt et al. 2001; Fritzsche et al. 1987; Kier et al. 1988; Tripathi et al. 1992). Possible degeneration or torsion of the undescended testis can be evaluated with heavily T2-weighted and dynamic subtraction contrast-enhanced images. Diffusion-weighted images may also be useful for this assessment. In case of intrapelvic testis, transaxial T1- and FS-T2-weighted images are obtained from the bottom of the scrotum to above the seminal vesicles. The examination should be extended to the lower poles of the kidneys when no testis is seen in the pelvis.
6. *Infertility.* The recommended protocol should implement FS-T2-weighted, heavily T2-weighted imaging in both the transaxial and coronal planes

and dynamic subtraction contrast-enhanced imaging in the coronal plane. Atrophy and degeneration of intratesticular seminiferous tubules can be demonstrated with T2-weighted images (Jhaveri et al. 2010; Simpson et al. 2009). The relationship between varicoceles and infertility (Costabile et al. 1993) has been believed, and dynamic subtraction contrast-enhanced imaging could reveal subtle disruptions of the blood-testis barrier associated with infertility. Diffusion-weighted imaging may also provide information of testicular degenerative changes. However, further investigation should be needed.

7. *Hydrocele.* The recommended protocol should implement FS-T2-weighted, heavily T2-weighted imaging in both the transaxial and coronal planes. Fluid collection between the tunica vaginalis can be clearly demonstrated with heavily T2-weighted images.

6 Contraindications of MR Examination

In general, MR imaging is contraindicated for patients who have electrically, magnetically, or mechanically activated implants, such as cardiac pacemakers, implantable cardiac defibrillators, cochlear implants, neurostimulators, bone-growth stimulators, and implantable drug infusion pumps (Hricak et al. 1995; Shellock 1992). Ferromagnetic or metallic biomedical implants or foreign bodies (including various kinds of vascular clips, skin staples, prosthetic heart valves, and orthopedic implants and devices) are also under contraindication of MR imaging due to possible danger of dislodgement or movement (Hricak et al. 1995; Shellock and Crues 1988). In addition, such objects may be subject to heating and induction of electrical currents. In contrast, patients with non-ferromagnetic or minimally ferromagnetic implants or devices can safely undergo MR imaging.

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