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RESEARCH

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Diffusion-weighted imaging and conventional magnetic resonance imaging for detection of non-palpable undescended testis

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Abstract

Background: MRI is noninvasive imaging tool and does not imply ionizing radiation and applies multiplanes images, but it is sometimes less efficient in locating intraabdominal functioning testicles and it fails to locate most of the atrophied testicles. Our aim in this study was to assess the value of the combined conventional MR imaging and DWI in the detection of non-palpable undescended testes in pediatric patients and correlate the results with the laparoscopic finding.

Results: This prospective study was carried out from January 2020 to February 2022 on 60 pediatric patients with 68 non-palpable undescended testes referred from Urology department to the radiodiagnosis and medical imaging department at our institute for MR imaging evaluation of clinically diagnosed non-palpable undescended testis, and their age ranged from 6 months to 17 years with mean age of 4.24 ± 4.67 years. The conventional MRI sensitivity was 85.71%, specificity was 100%, NPV was 60%, and PPV was 100% with accuracy of 88.23%. The combined DWI and MRI sensitivity was 92.86%, specificity was 100%, NPV was 75%, and PPV was 100% with accuracy of 94.12%. DWI was able to detect all viable abdominal testes, while only detecting 26 (out of 28) inguinal testes. Combined assessment was able to detect all viable abdominal and inguinal testes.

Conclusions: Combined DWI with a high *b* value and conventional MRI including T1WI, T2WI and fat-suppression T2WI showed considerable diagnostic performance compared to conventional MRI alone improving the preoperative sensitivity and accuracy of detection of non-palpable undescended testes.

Keywords: Undescended testes, Ultrasonography, Diffusion-weighted imaging

Background

Cryptorchidism (undescended testis) is the most common genital disorder recognized at birth. Undescended testes (UDTs) occur in 1–3% of full-term and up to 45% of preterm male neonates [1].

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About 20% of undescended testes are non-palpable [2]. For non-palpable testes, 30% are found at the inguinoscrotal region, and 55% are found intraabdominal, with only 15% absent or vanishing [3].

The basic reasons for treatment of undescended testis are increased probable risks of testicular malignancy, infertility, together with testicular torsion and associated inguinal hernia [4].

Different imaging techniques have been implied in localizing non-palpable UDTs preoperatively and include

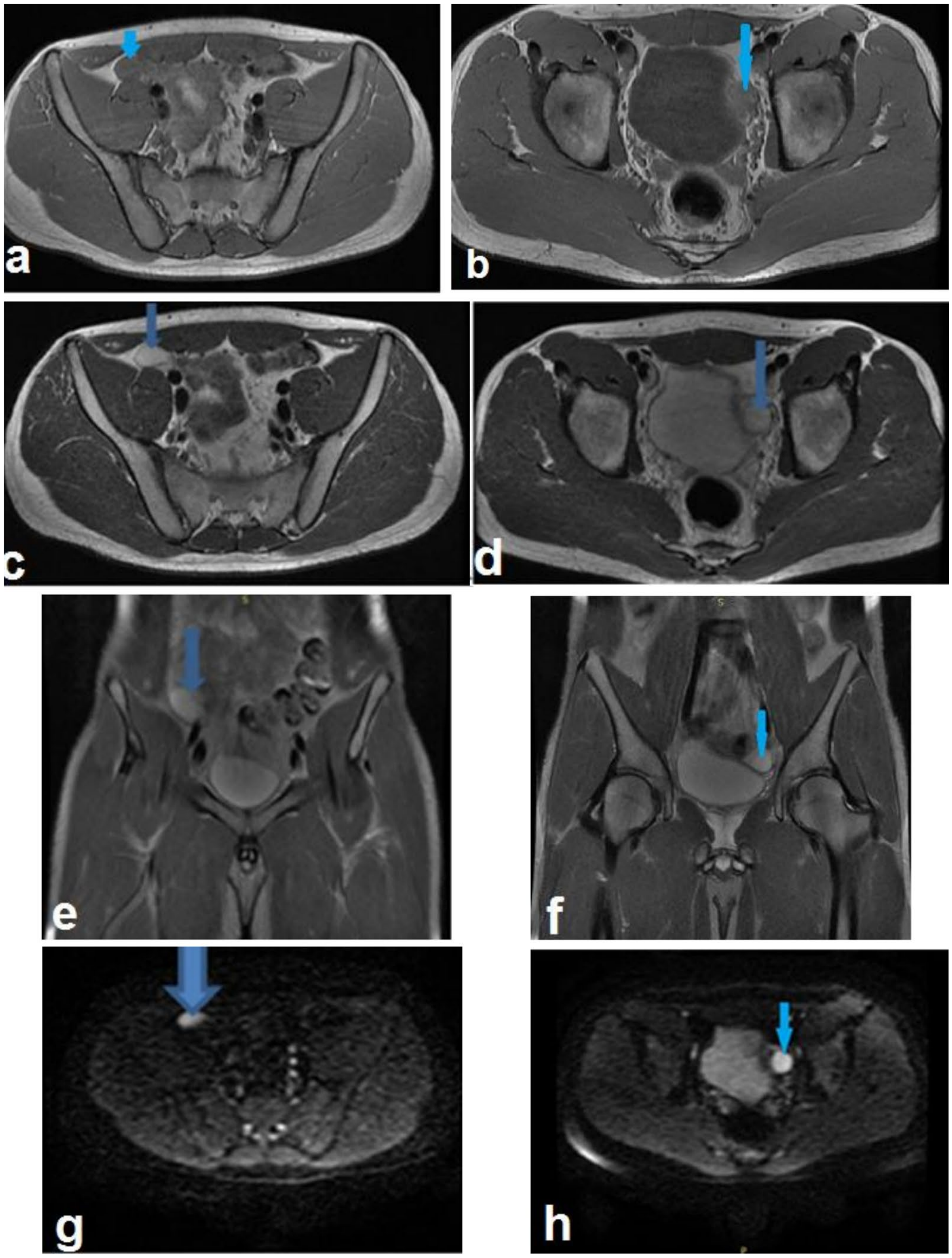

Fig. 1 A seventeen-year-old boy with bilateral non-palpable undescended testes since birth. *MRI findings* **a**, **b** axial T1-weighted image **c**, **d** axial T2-weighted image **e**, **f** coronal T2-weighted image showing bilateral intraabdominal undescended testes; the right one is seen in right iliac fossa and measuring about 3 × 1.3, and the left one is seen supravesicle and measuring 2 × 2 cm. They display iso-intense signal on T1WI and hyper-intense signal on T2WI. *DWIs finding*: **g**, **h** axial diffusion-weighted image showing restricted diffusion of both undescended testes *b* value = 800 s/mm^2. *Final diagnosis*: Bilateral low intraabdominal UDT. *Surgical findings*: Laparoscopy confirmed the MRI findings with lateral staged orchiopexy were done

ultrasonography (US), computed tomography (CT), conventional magnetic resonance imaging (MRI), magnetic resonance angiography (MRA) and magnetic resonance venography (MRV), with varying limitations including invasiveness, expense, the risk of radiation and contrast medium, with the need to use sedation [5].

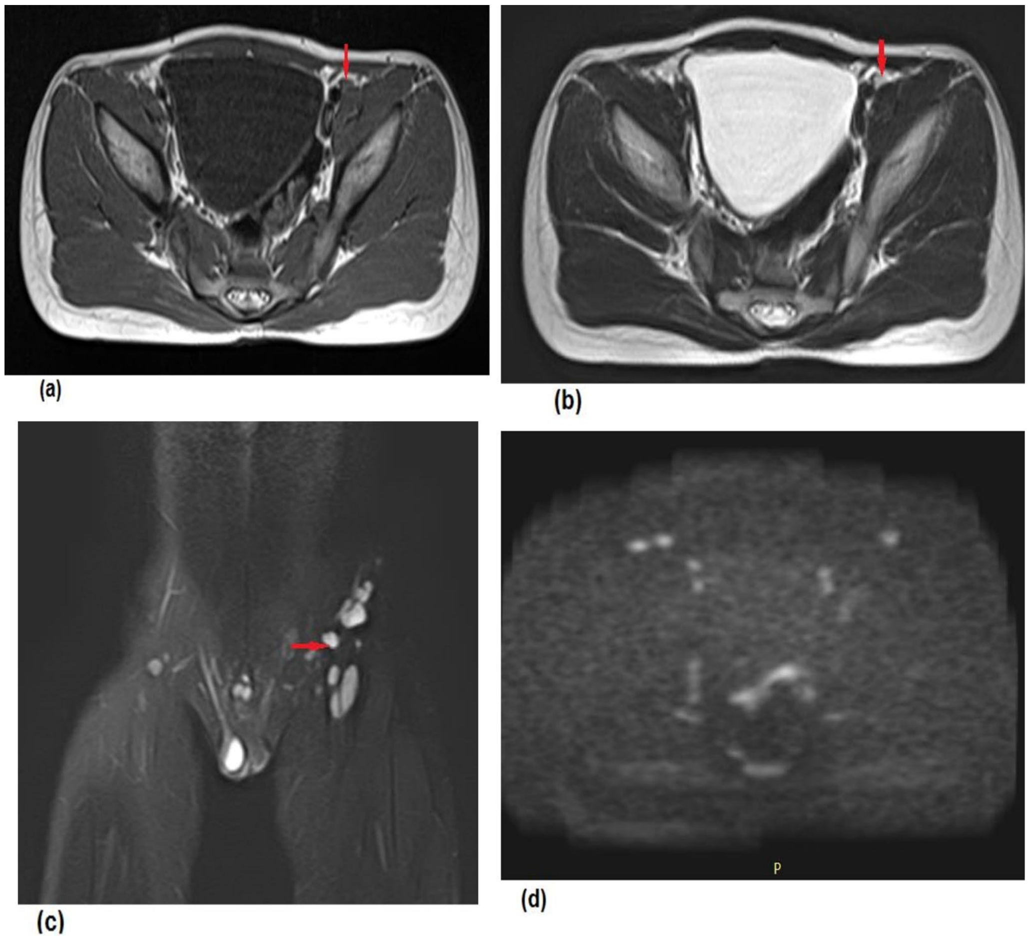

Fig. 2 A five-year-old boy complaining of left non-palpable undescended testis since birth. *MRI findings* **a** axial T1-weighted image, **b** axial T2-weighted image, **c** coronal STIR image showing left atrophic undescended testis seen in the left iliac region lateral to the iliac vessels measure 5.45 × 3.6 mm; it displays hypo-intense signal on T1W1, hyper-intense signal T2W2 and hyper-intense signal on STIR. *DWIs finding*: **d** Axial diffusion-weighted image the left undescended testis not seen at *b*-value = 800 s/mm^2. *Final diagnosis*: left atrophic low intraabdominal UDT. *Surgery*: Laparoscopy revealed atrophic intraabdominal testis and orchiectomy was done

Conventional MRI has low sensitivity for the localization of non-palpable UDT. It has evidently low efficiency in the detection of intraabdominal functioning testes. Furthermore, it fails to locate most of the atrophied testes, so the utilization of conventional MRI is less reliable in distinguishing children needing surgery from those who do not. Conventional MRI alone is not advantageous, and additional study is needed [6].

Diffusion-weighted imaging (DWI) as a noninvasive investigation is used to increase the preoperative sensitivity in identifying non-palpable UDT and facilitate the characterization of tissues at the microscopic level in a mechanism different from T1 and T2 relaxation [7].

In DWI technique, information is extracted on the diffusion of water molecules, which reflects the degree of tissue cellularity. The degree of restriction of water diffusion in biologic tissue is conversely related to cellularity of the tissue and the integrity of cell membranes. The motion of water molecules is more restricted in tissue with the high cellularity associated with numerous intact cell membranes [8].

The aim of the study is to evaluate the diagnostic performance of diffusion-weighted imaging and conventional magnetic resonance imaging for detection of non-palpable undescended testes before laparoscopy and correlate the radiological and laparoscopic finding.

Methods

This prospective study was carried on 60 male patients with 68 non-palpable undescended testes (unilateral in 52 cases and bilateral in 8 cases) whom age ranged from 6 months to 17 years old with mean age of

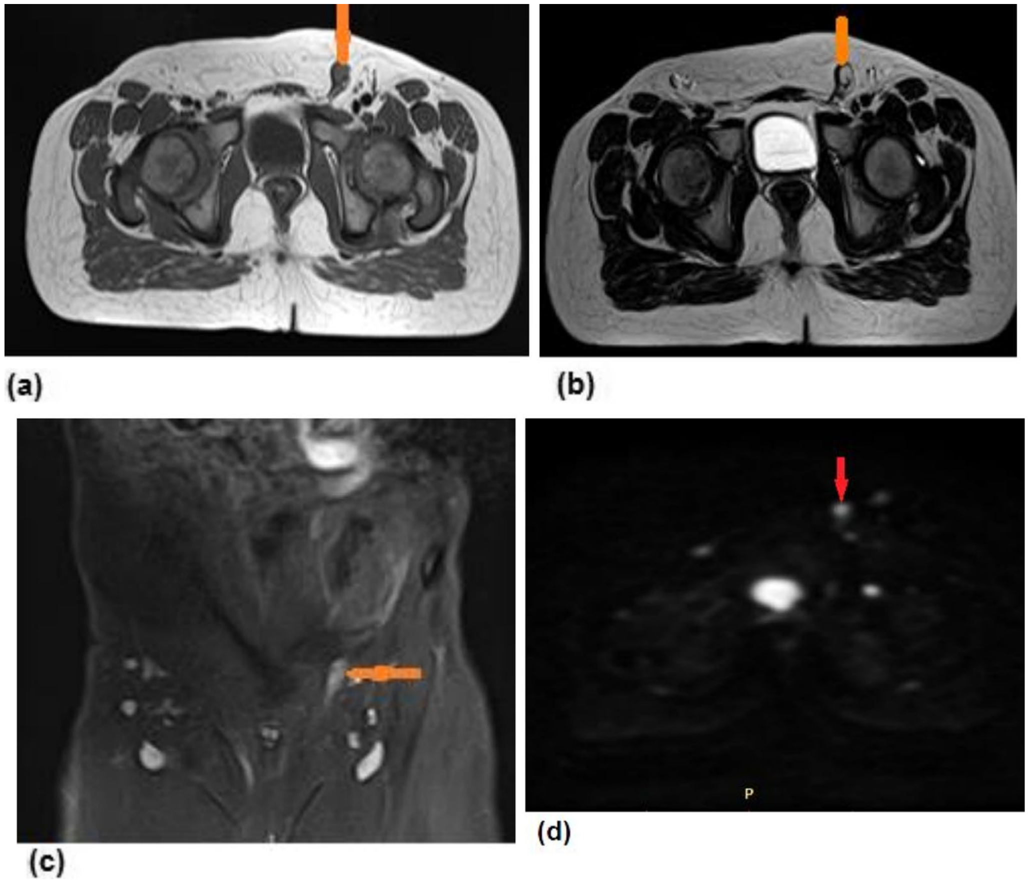

Fig. 3 A seven-year-old boy complaining of left non-palpable undescended testis since birth. MRI findings: **a** axial T1-weighted image, **b** axial T2-weighted image, **c** coronal STIR showing left undescended testes seen in the left inguinal canal at the internal ring measuring 9.88 × 8.75 mm ; it displays hypo-intense signal on T1W1, hyper-intense signal on T2W1 and hyper-intense signal on STIR. *On DWIs*: **d** axial diffusion-weighted image shows restricted diffusion at *b* value = 800 s/mm^2. *Final diagnosis*: left inguinal UDT. *Surgical findings*: laparoscopy confirmed the MRI findings, and left orchiopexy was done

(4.24 ± 4.67 years) at the period between January 2020 and February 2022. They were referred from Urology department to the Radiodiagnosis and medical imaging department at our institute for MR imaging evaluation of clinically diagnosed non-palpable undescended testes.

Inclusion criteria Patients diagnosed with undescended non-palpable testis unilateral or bilateral by clinical examination and US before undergoing laparoscopy.

Exclusion criteria Patients have hypospadias and/or micro-penis, and who have a heart pacemaker, an aneurysm clip in their brain, or who have a metallic foreign body in their eye. Older children with severe claustrophobia and patients who refuse the examination.

Ethics committee approved this study, and informed consent was obtained from all patients or their guardians. Privacy and confidentiality of all patient's data were guaranteed, and all data provision were monitored and used for security purpose only.

All patients in this study were submitted to the following:

1. Full history taking.
2. Clinical examination was done by qualified and trained clinicians in the urology department.
3. Ultrasound (Inguinoscrotal and abdominopelvic).
4. MRI examination: MRI was performed on a 1.5T *GE Signa* (General Electric, Milwaukee, WI, USA) closed configuration.

All patients were subjected to the following protocols:

MRI scanning, using the following parameters in Table 1:

- Axial and coronal turbo spin-echo T1- and T2-weighted image sequence.

Table 1 Detailed imaging parameters

MRI protocol sequences	TR (ms)	TE (ms)	Matrix	FOV* (mm)	No. of acquisitions (NXA)	No. of slices	Slice thickness (mm)	Inter-slice gap (mm)
Axial T1	450–650	10–16	256 × 256	300–350	2–5	25	7 mm	1.5 mm
Axial T2	3000–4000	80–100	256 × 256	300–350	2–5	25	3–5	0.5–1
Axial T2 STIR	3000–4000	80–100	256 × 256	300–350	2–5	25	3–5	0.5–1
Coronal T1	400–600	10–20	256 × 256	300–350	5	25	3–5	0.5–1
Coronal T2	4000–7000	110–120	256 × 256	300–350	5	25	3–5	0.5–1
Coronal T2 STIR	3000–4000	80–100	256 × 256	300–350	5	25	3–5	0.5–1
Diffusion	3000–4000	70–90	256 × 256	250–300	5	25	3–5	0.5–1

- Axial and coronal fat-suppressed turbo spin-echo T2-weighted image sequence.
- Axial DWI with b values of 50, 400, and 800 s/mm^2.
- Thirty children below 5 years were sedated with chloral hydrate syrup, and the dose was 1 ml/kg body weight and well immobilized during the MRI examination.

Image analysis

All MRI images including diffusion-weighted image sequences were transferred to an independent workstation (Signa Explorer, GE MR extended workspace). MR images reviewed for the presence or absence and the location of UDT.

First the diffusion-weighted images, including the images with b value of 50, 400 and 800 s/mm^2, were reviewed alone, then the conventional MR images separately and finally the combined DW and conventional MR images.

Image interpretation

The interpretation of the images was done by two expert radiologist who had experience 10 and 6 years.

Laparoscopic examination and open exploration

During laparoscopy, the abdominal spaces were inspected by laparoscopic tools. The blood vessels, nature of the testes and termination of the vas were determined. If the vas and testicular vessels entered the internal inguinal ring, an open inguinal exploration and conventional orchidopexy were done. Laparoscopic orchiectomy was done for the atrophic testes.

We performed laparoscopic observation and at the same cession subsequent laparoscopic orchidopexy for intraabdominal testes, open orchidopexy for intracanalicular testes and open or laparoscopic orchidectomy for testicular nubbins, ending blindly at the cord structure depending on the presence and location of the testes.

The results of MRI were considered positive when a testis was identified before the operation and finally diagnosed by surgeon.

Statistical analysis

All data were collected, tabulated and statistically analyzed using SPSS 22.0 for windows (SPSS Inc., Chicago, IL, USA) and MedCalc 13 for windows (MedCalc Software bvba, Ostend, Belgium).

Results

The age of patients ranged from 6 months to 17 years with mean ±SD=4.24 ± 4.67 years. Regarding age distribution, most patients were less than 24 months (46.7%). The least age seen was from 24 month to less than 48 months found in (10 %) patients (Table 2).

As illustrated in Table 3, testes detected intracanalicular by ultrasonography were 28 (41.17%) testes, MRI: 30 (44.11%) testes, DWI: 26 (38.23%) testes, MRI and DWI 30 (44.11%) testes and by laparoscopy 30 (44.11%) testes. Testes detected low intraabdominal by ultrasonography were 12 (17.64%) testes, MRI: 16 (23.5%) testes, DWI: 16 (23.5%) testes, MRI and DWI 18 (26.47%) testes and by laparoscopy 18 (26.47%) testes. Testes detected high intraabdominal by MRI were 2 (2.94%), DWI: 4 (5.88%), MRI and DWI: 4 (5.88%) and by laparoscopy: 8 (11.76 %) testes.

In the studied patients, 16 testes were not detected by US examination but detected by laparoscopy (false

Table 2 Age distribution of studied patients ($n = 60$)

Variables	Patients ($n = 60$)	
Age (months)	n	%
0–< 24 months	28	46.7
24–< 48 months	6	10
48–< 72 months	12	20
> 72 months	14	23.33

Table 3 Comparison of conventional MRI, DWI, laparoscopy and US results according to site

Site	US		MRI		DWI		MRI and DWI		Laparoscopy	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
Intracanalicular	28	41.17	30	44.11	26	38.23	30	44.11	30	44.11
Low intraabdominal	12	17.64	16	23.5	16	23.5	18	26.47	18	26.47
High intraabdominal	0	0.00	2	2.94	4	5.88	4	5.88	8	11.76
Total	40	58.82	48	70.58	46	67.64	52	76.47	56	82.3

Table 4 Comparison of US, MRI, DWI, combined MRI and DWI results according to laparoscopy findings

	Laparoscopy				*P*
	Absent ($n=12$)		Detected ($n=56$)		
	N	%	*N*	%	
US					.0003
Absent	8	66.67	16	28.57	
Detected	4	33.3	40	71.42	
MRI					.001
Absent	12	100	8	14.28	
Detected	0	0	48	85.71	
DWI					.0001
Absent	10	83.3	10	17.9	
Detected	2	16.7	46	82.1	
DWI and MRI					.000
Absent	12	100	4	7.1	
Detected	0	0	52	92.9	

negative) and 8 testes not detected by US examination and confirmed by laparoscopy (true negative). Forty testes were detected by US examination and confirmed by Laparoscopy (true positive) and 4 testes detected by US examination but not detected by laparoscopy (false positive) (Table 4).

Eight testes were not detected by MRI examination but detected by laparoscopy (false negative) and 12 testes not detected by MRI examination and confirmed by laparoscopy (true negative). Forty-eight testes were detected by MRI examination and confirmed by laparoscopy (true positive) (Table 4).

In our study, diffusion-weighted imaging at different *b* values 50,400,800 s/mm^2 was performed to all patients.

In images with *b* value 50 s/mm^2, fluid-containing structures such as the bowel contents, urinary bladder and gall bladder have high signal intensity. In images with a *b* value of 800 s/mm^2, the bowel contents are suppressed, and the testes have high signal intensity. Therefore, we can easily visualize undescended testes using DWI with *b* value of 800 s/mm^2 than *b* value of 400 s/mm^2, so in our study we depend on images with *b* value 800 s/mm^2 in identification of the undescended testes.

In the studied patients, 10 testes were not detected by DWI examination but detected by laparoscopy (false negative) and 10 testes not detected by DWI examination and confirmed by laparoscopy (true negative). Forty-six testes were detected by DWI examination and confirmed by laparoscopy (true positive), and two testes were detected by DWI examination but not detected by laparoscopy (false positive) (Table 4).

Four testes were not detected by combined DWI and MRI examination but detected by laparoscopy (false negative) and 12 testes not detected by combined DWI and MRI examination and confirmed by laparoscopy (true negative). Fifty-two testes were detected by combined DWI and MRI examination and confirmed by laparoscopy (true positive) (Table 4) (Figs. 1, 2 and 3).

The conventional MRI sensitivity was 85.71%, specificity was 100%, NPV was 60%, and PPV was 100% with accuracy of 88.23%; however, the combined DWI and MRI sensitivity was 92.86%, specificity was 100%, NPV was 75% and PPV was 100% with accuracy of 94.12% (Table 5).

DWI was able to detect all viable abdominal testes, while only detecting 26 (out of 28) inguinal testes. Combined assessment was able to detect all viable abdominal and inguinal testes (Table 6).

Discussion

Cryptorchidism is a common pediatric anomaly that often needs early surgical management. The identification of the presence or absence and location of testicles preoperatively can help to determine the optimal type of procedure and allow for appropriate advance planning. In the case of absent or vanishing testicles, imaging findings could preclude the need for surgical exploration completely [9].

Different imaging techniques have been used in localizing non-palpable UDTs before laparoscopy and include ultrasonography (US), computed tomography (CT), conventional magnetic resonance imaging (MRI), magnetic resonance angiography (MRA) and magnetic resonance venography (MRV) with varying limitations

Table 5 Comparison of diagnostic value of conventional MRI and diagnostic value of combined DWI and MRI

Statistic	Diagnostic value of conventional MRI		Diagnostic value of combined DWI and MRI	
	Value (%)	95% CI (%)	Value (%)	95% CI (%)
Sensitivity	85.71	67.33–95.97	92.86	76.50–99.12
Specificity	100	35.88–99.58	100	54.07–100
Positive predictive value (PPV)	100	79.94–99.31	100	–
Negative predictive value (NPV)	60	32.03–76.83	75.00	44.10–91.94
Accuracy	88.23	68.94–95.05	94.12	80.32–99.28

Table 6 Viability of detected undescended testes

Site	DWI		MRI and DWI		Laparoscopy	
	N	%	*N*	%	*N*	%
Inguinal	26	38.2	28	41.17	28	41.17
Low Intraabdominal	16	23.5	16	23.5	16	23.5
High Intraabdominal	4	5.88	4	5.88	4	5.88
Total	46	67.64	48	70.58	48	70.58

including invasiveness, expense, the risk of radiation and contrast medium, together with the need for sedation [10].

Diagnostic laparoscopy has been accepted as the most dependable diagnostic technique for localizing non-palpable testes with nearly 100% sensitivity and specificity [11, 12]. So we used laparoscopy as the gold standard for this study.

Fat-suppression T2WI sequence is more sensitive to inflammation and water content by suppressing fat, so providing a sharp contrast between the testes and the surrounding tissues [6].

Diffusion-weighted imaging is an advancing technique with the potential to improve characterization of the tissue when the findings are interpreted in coincidence with those obtained from conventional MRI sequences. Hyper-intensity of normal testicular parenchyma on DW sequences is due to the complex histology of normal testicular tissue. The presence of densely packed seminiferous tubules and interstitial stroma in between results in a restricted diffusion of water molecules. The bright signal intensity of the testes on DWI permits easier recognition [13].

Our study included 60 patients with 68 UDT (eight patients had bilateral UDT), who were clinically diagnosed with non-palpable UDT. MRI including T1WI, T2WI, STIR and diffusion-weighted images at different b values 50, 400 and 800 s/mm^2 was performed to all patients. The results of MRI were compared to laparoscopic findings.

In the present study, 13.3% of non-palpable testes were bilateral and the remaining were unilateral; 60% were in the left side, while 26.7% were in the right side. This was supported by Al-Kayat [14] with 69.2% of undescended testis on left side and 30.8% on right side, while Ali and Mansour [6] recorded 54.5% of undescended testes in the left side and 45.5% in the right side.

The age of the patients in the current study ranged from 6 months and 17 years with mean age 4.24 ± 4.67 years, while Abd Elgawad et al. [15] documented age range from 2 to 15 years with mean age 8 years, Emad-Eldin et al. [16] stated age range from 5 months to 18 years with mean age 7.5 years, and Ali and Mansour [6] reported age range from 15 months to 15 years with mean age 6.4 years. Al Wakeel et al. [17] recorded age range from 5 months and 25 years of age (mean = 9.86 ± 6.91 years).

Regarding the distribution of the studied cases according to the post-surgical findings in this study, location of UDT was inguinal (n = 30, 44.11%), low intraabdominal (n = 18, 26.47%), high intraabdominal (n = 8, 11.76%), whereas the testes were vanished (absent) in 12 cases (17.65%), which is like the distribution reviewed by Abd Elgawad et al. [15] which was 49% intracanalicular, 28.3% low intraabdominal, 11.3% high intraabdominal and 11.3% absent. Emad-Eldin et al. [16] concluded 38% intracanalicular, 13% low intraabdominal, 11% high intraabdominal and 38% vanishing/absent testes. and Ali and Mansour [6] stated 30.3% intracanalicular, 36.36% low intraabdominal, 0.06% high intraabdominal and 27.27% vanishing/absent testes, while Kato et al. [18] mentioned that 20.6% of the studied testes were intracanalicular, 20.6% were intraabdominal and 58.7% were vanishing/absent, and Kantarci et al. [13] revealed that 50% of the studied testes were intracanalicular, 29% low intraabdominal, 10.5% high intraabdominal, 2.6% atrophic and 10.5% were absent.

Muna et al. [19] declared that ultrasonography is more precise than clinical examination in the localization of undescended testes in children preoperatively with sensitivity 83.3% specificity 100% and accuracy 90%, and this is true for intracanalicular testis; however, US cannot reliably confine the intraabdominal testis or atrophic testis.

This was in concurrence with findings of Tasian and Copp [20] who proved that US was poor at localizing non-palpable undescended testes, with reported sensitivity and specificity 45% and 78%, respectively. They stated that ultrasound was unable to differentiate non-viable nubbins from inguinal tissue and was adversely affected by the presence of bowel gas.

Krishnaswami et al. [21] mentioned that MRI has a fairly low sensitivity for identifying the presence of non-palpable cryptorchid testicles (sensitivity of 62%). When testicles are identified, MRI is poor at locating both atrophied and intraabdominal testicles but performs reasonably well (expected sensitivity of 86%) in locating those in the inguinoscrotal regions.

Kantarci et al. [13] assumed that conventional MRI had a high accuracy of 84%, sensitivity of 85% and high specificity of 100% for diagnosing UDT.

Emad-Eldin et al. [16] recorded a higher sensitivity of 90%, specificity of 93% and accuracy of 91%. Only conventional MRI techniques were used in those studies.

In our study, we assumed that conventional MRI had an accuracy of 88.23%, sensitivity of 85.71% and specificity of 100% for diagnosing UDT. MRI failed to detect four atrophic intraabdominal cases which were confirmed by laparoscopy.

In present study, we compared the diagnostic performance of each MRI sequences for identification localization of UDT. First the diffusion-weighted images were reviewed alone, then the conventional MR images separately and at the end the combined DWI and conventional MR images.

Using DWI alone, we accurately localized (46/68) testes, and they reported accuracy, sensitivity and specificity of 82.35%, 82.14% and 83.3%, respectively. DWI can be used as indicator for testis viability.

In present study, the differentiation between the lymph nodes at the inguinal region and testes using diffusion-weighted imaging was not so easy in some cases as both structures display similar signal intensity. However, this problem was resolved using fat-suppressed T2-weighted imaging, as lymph nodes were seen at a lower signal intensity compared with the testes.

Using conventional MRI alone, we localized (48/68) testes. They reported accuracy, specificity and sensitivity of 88.23, 100 and 85.71%, respectively. However, when we added DWI to conventional MRI, we localized (52/68) testes and both sensitivity and accuracy were greater (sensitivity 92.86%, specificity, 100% and accuracy 94.12%).

This agreed with the previous findings of Kantarci et al. [13] who investigated the diagnostic performance of DWI and MRI in localizing non-palpable undescended testes. They demonstrated that when using conventional MRI alone, they identified 29/38 testes with a sensitivity of 85%, a specificity of 100% and accuracy of 84%, respectively. Using DWI alone, they found a sensitivity of 82%, a specificity of 75% and accuracy of 84%. A combination of DWI and MRI enabled the accurate identification of 31/38 testes with a sensitivity of 88%, accuracy of 86% and specificity of 100% [13].

Awad et al. [1] declared that conventional MRI showed sensitivity of 79.31%, specificity of 100% and overall accuracy of 81.82%. DWI had higher sensitivity (82.76%) but lower specificity (75%) and similar overall accuracy (81.82%) compared to conventional MRI. Combined assessment had the highest sensitivity (86.21%), specificity (100%) and accuracy (87.88%).

Emad-Eldin et al. (16) recorded higher results; they confirmed that when MRI was used alone, a sensitivity of 93%, a specificity of 87% and accuracy of 91.5% were reported. Adding DWI to conventional MRI, the results increased to a sensitivity of 93%, a specificity of 100% and accuracy of 95.70%.

Limitation of the study

First, patients younger than 6 years needed sedation or general anesthesia for an optimal MRI examination. Second, there was a lack of enteric contrast, which plays an important role in the detection of intraabdominal undescended testes. We believe that with technical improvements, some of these limitations may be overcome. The limitations of DWI include its poor anatomic location and spatial resolution. In addition, particularly with the use of high *b* values anatomic distortion increases.

Recommendation

In patients with non-palpable testes, we recommend adding the DWI at high *b* value with conventional MRI to increase the preoperative diagnostic accuracy of identifying and detecting viability of non-palpable undescended testes.

Conclusions

The addition of DWI with a high *b* value to conventional MRI including T1WI, T2WI and fat-suppression T2WI showed greater diagnostic performance compared to conventional MRI alone improving the sensitivity and accuracy of detection of non-palpable undescended testes preoperatively.

Abbreviations

MRI: Magnetic resonance imaging; DWI: Diffusion-weighted imaging; UDTs: Undescended testes; MRA: Magnetic resonance angiography; MRV: Magnetic resonance venography; US: Ultrasonography; FOV: Field of view.

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Author contributions

NE suggested the research idea, ensured the original figures and data in the work, minimized the obstacles to the team of work, correlated the study concept and design and had the major role in analysis, and MB supervised the study with significant contribution to design the methodology, manuscript revision and preparation. SN correlated the clinical data of patient and matched it with the findings and drafted and revised the work. RD collected data in all stages of manuscript and performed data analysis. All authors read and approved the final manuscript for submission.

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Availability of data and materials

The authors confirm that all data supporting the finding of the study are available within the article and the raw data and data supporting the findings were generated and available at the corresponding author on request.

Declarations

Ethics approval and consent to participate

Informed written consents were taken from the patients and healthy volunteers, and the study was approved by ethical committee of Tanta university hospital, faculty of medicine (33455/10/19).

Consent for publication

All participants included in the research gave written consent to publish the data included in the study. Authors accepted to publish the paper.

Competing of interests

The authors declare that they have no competing of interests.

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