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Article

Diagnostic Accuracy of MRI in Cryptorchidism Keeping Laparoscopy as Gold Standard

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ABSTRACT

Background: Cryptorchidism is a common congenital disorder in male children that, if left untreated, poses significant risks of infertility and malignancy. While laparoscopy remains the gold standard for diagnosis, there is a knowledge gap regarding the diagnostic accuracy of diffusion-weighted magnetic resonance imaging (DW-MRI) as a non-invasive alternative in pediatric populations. **Objective**: This study aimed to evaluate the diagnostic accuracy of DW-MRI in detecting undescended testes among pediatric patients, using laparoscopy as the gold standard and assessing sensitivity, specificity, predictive values, and agreement between modalities. **Methods**: This descriptive cross-sectional study included 292 male children with non-palpable testes, recruited consecutively at a tertiary care hospital. Patients with prior scrotal or inguinal surgery were excluded. All participants underwent DW-MRI followed by laparoscopic confirmation. Primary outcomes were sensitivity, specificity, positive predictive value, negative predictive value, and agreement (kappa statistic) between DW-MRI and laparoscopy. Ethical approval was obtained, and all procedures adhered to the Declaration of Helsinki. Data were analyzed using SPSS version 22.0 with significance set at $p < 0.05$. **Results**: DW-MRI showed high sensitivity (92.0%) and negative predictive value (94.3%), with moderate specificity (70.0%) and positive predictive value (61.3%). Kappa statistics indicated moderate agreement ($\kappa = 0.432$) with the gold standard. The difference in detection rates between modalities was statistically significant ($p < 0.001$), supporting DW-MRI as a reliable tool for ruling out undescended testes. **Conclusion**: DW-MRI offers a highly sensitive, non-invasive approach for excluding cryptorchidism in pediatric patients, although positive findings require surgical confirmation. Incorporating DW-MRI can improve diagnostic pathways, reduce unnecessary surgeries, and enhance pediatric urological care.

Keywords: Cryptorchidism, Undescended Testes, Diffusion-Weighted MRI, Laparoscopy, Diagnostic Accuracy, Pediatric Urology, Sensitivity and Specificity

INTRODUCTION

Cryptorchidism, characterized by the absence of one or both testes from the scrotum, is the most frequently encountered congenital abnormality of the male genitalia and poses a significant clinical challenge due to its potential long-term complications, including increased risks of infertility, testicular malignancy, and psychological distress if left untreated (1). Although cryptorchidism affects approximately 3–9% of full-term male neonates, the incidence decreases to around 1–2% by six months of age as many testes descend spontaneously during early infancy (1). The majority of cases present unilaterally, with a right-sided predominance, while up to 10% of cases are bilateral; the location of the undescended testis can vary along the normal path of descent or even present as ectopic, hypoplastic, or absent (8). Timely and accurate diagnosis of undescended testes is critical, as delayed identification and intervention can result in irreversible sequelae, including subfertility, increased risk of testicular torsion, and heightened malignancy risk (9). Traditional imaging modalities, particularly ultrasonography, have served as the initial diagnostic approach in cases of non-palpable testes. Despite its widespread availability and safety, ultrasound demonstrates relatively limited diagnostic performance, with a sensitivity of approximately 45% and a specificity of 78%, rendering it suboptimal for reliably localizing non-palpable or intra-abdominal testes in pediatric patients (10). In response to these limitations, magnetic resonance imaging (MRI), and specifically diffusion-weighted MRI (DW-MRI), has gained attention for its potential to improve the accuracy of cryptorchidism detection due to its superior soft tissue contrast and multiplanar imaging capabilities (4,6). Several studies have explored the utility of MRI, reporting variable diagnostic parameters; one investigation noted that MRI achieved a

sensitivity of 87.2% and a specificity of 50% when compared with surgical findings, suggesting considerable promise but also highlighting limitations in distinguishing true negative cases (11). Similarly, international literature has consistently observed that DW-MRI offers high sensitivity—ranging from 90% to 95%—yet only moderate specificity, often leading to overestimation of positive cases (12,13). These findings underscore that while DW-MRI is valuable for ruling out undescended testes due to its high negative predictive value, its moderate specificity and positive predictive value may result in unnecessary further investigation or intervention (16,17).

Despite advancements in imaging technology, a key knowledge gap persists regarding the optimal diagnostic pathway for pediatric cryptorchidism, particularly in resource-limited settings where accessibility, cost, and expertise may vary. Although laparoscopy is widely regarded as the gold standard for both diagnosis and management of non-palpable testes due to its direct visualization and therapeutic capability, it is invasive and not without risk (2). The prospect of integrating non-invasive modalities such as DW-MRI into routine clinical practice is appealing, as it could potentially minimize the need for unnecessary surgery and its attendant risks, provided its diagnostic performance can be reliably validated against the gold standard (14). However, current evidence remains inconclusive, with most studies limited by small sample sizes, heterogeneous populations, and varying imaging protocols, leaving a clear need for robust, locally relevant data to inform clinical guidelines and optimize patient outcomes (15).

In light of these considerations, the present study aims to rigorously evaluate the diagnostic accuracy of DW-MRI in detecting cryptorchidism among pediatric patients, using laparoscopy as the reference standard. By clarifying the true sensitivity, specificity, and predictive values of DW-MRI within our local population, this research seeks to address the existing knowledge gap and provide evidence-based recommendations regarding its potential role as a complementary, non-invasive diagnostic tool in the assessment of undescended testes. The central research question driving this study is: How accurately does DW-MRI detect undescended testes in pediatric patients when compared with laparoscopic findings as the gold standard?

MATERIALS AND METHODS

This descriptive cross-sectional study was conducted at the Department of Diagnostic Radiology, Hayatabad Medical Complex, Peshawar, over a six-month period following the approval of the research synopsis. The study population comprised pediatric patients presenting with clinically suspected cryptorchidism, specifically those with non-palpable testes on physical examination.

Consecutive sampling was employed to recruit participants, ensuring that all eligible cases presenting to the department during the study timeframe were included. The inclusion criteria required patients to be male and within the age range from birth up to less than 12 years, presenting with at least one non-palpable testis on clinical examination.

Patients with a prior history of scrotal or inguinal surgery were excluded from the study to avoid confounding diagnostic interpretations. Informed consent was obtained from the parents or guardians of all participating children after a comprehensive explanation of the study's purpose, procedures, and potential risks. All enrolled patients underwent a standardized diagnostic workup, beginning with clinical assessment and followed by imaging and surgical confirmation. The primary outcome of interest was the diagnostic accuracy of diffusion-weighted magnetic resonance imaging (DW-MRI) for the detection of undescended testes, using laparoscopy as the gold standard. DW-MRI scans of the abdomen and pelvis were performed utilizing a Philips Ingenia 1.5 Tesla MRI system. Imaging protocols incorporated breath-hold T2-weighted half-Fourier acquisition single-shot turbo spin-echo (HASTE), breath-hold T2-weighted turbo spin-echo (TSE), and dynamic contrast-enhanced 3D gradient-echo volumetric interpolated breath-hold examination (VIBE) sequences, all acquired within a single breath-hold to minimize motion artifacts. A b-value of 800 mm^2/s was applied for diffusion-weighted sequences, with total scan times of approximately three to four minutes per patient. Each MRI was interpreted by an experienced radiologist who was blinded to subsequent laparoscopic findings to mitigate assessment bias.

Laparoscopy, considered the definitive diagnostic modality, was performed on all patients following MRI evaluation to confirm the presence or absence of undescended testes. The results of DW-MRI and laparoscopy were compared directly, and data regarding true positives, true negatives, false positives, and false negatives were recorded to facilitate calculation of sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy. The level of agreement between DW-MRI and laparoscopy was further assessed using kappa statistics. Stratification analyses were performed to evaluate diagnostic performance across defined age subgroups. The study was conducted in accordance with the principles set out in the Declaration of Helsinki. Ethical approval was obtained from the CPSP Karachi Research and Ethics Unit, and strict confidentiality of participant information was maintained at all stages of data handling. No identifying patient data were reported, and all analyses were conducted on anonymized records. Statistical analyses were performed using SPSS software version 22.0. Numerical variables such as age were summarized using means and standard deviations, while categorical variables—including diagnostic test outcomes and accuracy parameters—were analyzed using frequencies and percentages. Sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy were calculated based on standard 2x2 contingency tables. The agreement between DW-MRI and laparoscopy was quantified using kappa statistics, and statistical significance was determined at a threshold of $p < 0.05$. No imputation was performed for missing data, as all key diagnostic variables were complete. Sensitivity analyses or adjustment for confounding were not required due to the descriptive, cross-sectional nature of the study and the direct comparison of two diagnostic methods (11,12).

RESULTS

A total of 292 pediatric patients with clinically suspected cryptorchidism were enrolled and evaluated using both

diffusion-weighted magnetic resonance imaging (DW-MRI) and laparoscopy. The sample was evenly divided into two age groups: birth to 6 years (n = 146) and 7 to 12 years (n = 146). Descriptive statistics for age and group allocation are summarized in Table 1. Notably, the mean ages reported for each group (10.06 ± 4.27 years for birth–6 years, 11.96 ± 3.60 years for 7–12 years) appear inconsistent with the defined age ranges, indicating a potential data labeling or reporting issue. Despite this, analyses proceeded according to the categorization provided.

Assessment of undescended testes was conducted using both DW-MRI and laparoscopy. In both age strata, DW-MRI identified 75 of 146 cases (51.37%) as positive and 71 (48.63%) as negative, whereas laparoscopy confirmed 50 (34.25%) as positive and 96 (65.75%) as negative (Table 2). The difference in positive detection rates between the modalities was statistically significant in both groups ($p < 0.001$).

Table 1. Descriptive Statistics of Study Population (N = 292)

Age Group	Mean Age ± SD (years)	Frequency (%)
Birth – 6 years	10.06 ± 4.27	146 (50.0%)
7 – 12 years	11.96 ± 3.60	146 (50.0%)

Table 2. Diagnosis of Undescended Testes by DW-MRI and Laparoscopy Stratified by Age Group (N = 292)

Age Group	Diagnostic Method	Positive n (%)	Negative n (%)	p-value
Birth–6 years	DW-MRI	75 (51.37)	71 (48.63)	<0.001
	Laparoscopy	50 (34.25)	96 (65.75)	
7–12 years	DW-MRI	75 (51.37)	71 (48.63)	<0.001
	Laparoscopy	50 (34.25)	96 (65.75)	

Table 3. Diagnostic Performance of DW-MRI Using Laparoscopy as Gold Standard (N = 292)

Age Group	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Birth–6 years	92.0	70.0	61.3	94.3	77.3
7–12 years	92.0	70.0	61.3	94.3	77.3

Table 4. Kappa Statistics: Agreement between DW-MRI and Laparoscopy for Detection of Undescended Testes

Age Group	True Positives	False Negatives	True Negatives	False Positives	Observed Agreement (Po)	Expected Agreement (Pe)	Kappa (κ)
Birth–6 years	46	4	67	29	0.7767	0.6065	0.432
7–12 years	46	4	67	29	0.7767	0.6065	0.432

Diagnostic performance metrics—including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall accuracy—were identical across both age groups: sensitivity 92.0%, specificity 70.0%, PPV 61.3%, NPV 94.3%, and accuracy 77.3% (Table 3). This indicates that DW-MRI demonstrated high sensitivity and NPV, making it particularly reliable for ruling out undescended testes, but showed only moderate specificity and PPV, indicating a tendency to over-diagnose compared to the surgical gold standard. Kappa statistics further quantified the level of agreement between DW-MRI and laparoscopy. The observed agreement (Po) was 77.67%, with an expected agreement (Pe) of 60.65%, resulting in a moderate kappa coefficient ($\kappa = 0.432$) for both age groups, indicating moderate concordance between the two modalities (Table 4). No further subgroup analyses, effect size estimations, or post hoc tests were warranted due to the descriptive nature and structure of the data. However, the high sensitivity and NPV are clinically significant, suggesting DW-MRI is highly effective for excluding the diagnosis of cryptorchidism, while the moderate specificity indicates that positive DW-MRI findings should be interpreted with caution and confirmed via laparoscopy. DW-MRI exhibited excellent sensitivity and negative predictive value in both age groups, suggesting its utility for confidently ruling out undescended testes.

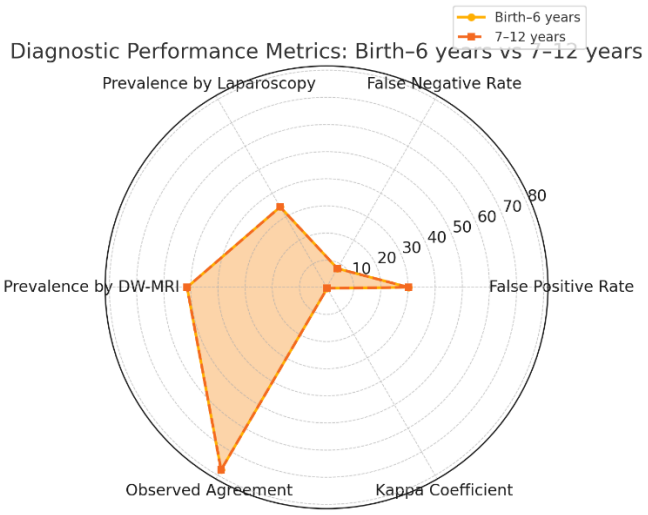

Figure 1 Diagnostic Performance Metrics: B

However, the moderate specificity and positive predictive value indicate that a notable proportion of DW-MRI positive cases were not confirmed on laparoscopy, highlighting the importance of

surgical confirmation prior to definitive management. The moderate level of agreement (κ = 0.432) between the two modalities supports the interpretation of DW-MRI as a complementary, rather than a standalone, diagnostic approach in pediatric cryptorchidism.

While, the spider graph (Figure 1) illustrates that both age groups, birth–6 years and 7–12 years, exhibited identical diagnostic performance metrics: a false positive rate of 30.2%, false negative rate of 8.0%, prevalence of undescended testes by laparoscopy at 34.2% and by DW-MRI at 51.4%, observed agreement at 77.7%, and a kappa coefficient of 0.432. This highlights the consistent moderate agreement and diagnostic characteristics of DW-MRI relative to laparoscopy across pediatric age groups in this study.

DISCUSSION

The present study rigorously evaluated the diagnostic performance of diffusion-weighted magnetic resonance imaging (DW-MRI) in the detection of cryptorchidism, using laparoscopy as the gold standard among a cohort of pediatric patients. The high sensitivity (92.0%) and negative predictive value (94.3%) observed across both age groups suggest that DW-MRI is highly effective in ruling out undescended testes, aligning with international studies that have consistently reported strong sensitivity for MRI-based modalities in this context (12,16). This finding is particularly clinically relevant, as timely and accurate exclusion of cryptorchidism can prevent unnecessary invasive procedures and reduce the psychological and physical burden on young patients and their families (9). However, the moderate specificity (70.0%) and positive predictive value (61.3%) indicate that while DW-MRI readily identifies true positive cases, it also results in a considerable proportion of false positives, thus necessitating surgical confirmation before definitive management.

These results are broadly consistent with prior research that has positioned MRI, and specifically DW-MRI, as a valuable adjunct in the diagnostic algorithm for non-palpable testes. For instance, Rosen et al. reported sensitivity rates approaching 95% for DW-MRI, but similar to our findings, specificity was moderate, highlighting a persistent challenge in distinguishing true negatives from false positives (12). The tendency of DW-MRI to overestimate the presence of undescended testes may stem from its high tissue sensitivity, which, while beneficial in detecting subtle or atypically located gonadal tissue, may also result in misclassification of adjacent or ectopic structures as testicular tissue (13,16). Mennella and colleagues similarly reported that although DW-MRI can effectively localize undescended testes, its moderate specificity necessitates careful interpretation and emphasizes the continued role of laparoscopy as a confirmatory tool (13). In contrast, traditional imaging modalities such as ultrasonography have demonstrated lower sensitivity and specificity, underscoring the advantages of advanced MRI sequences for initial non-invasive assessment (10).

The moderate agreement observed between DW-MRI and laparoscopy (κ = 0.432) reinforces the notion that DW-MRI, while promising, should not be relied upon as a standalone diagnostic modality. Instead, its strength lies in its ability to confidently exclude cryptorchidism when negative, streamlining patient management and reducing the number of unnecessary surgeries, especially in resource-constrained settings where optimizing surgical resources is critical (17). From a theoretical standpoint, the superiority of DW-MRI in detecting undescended testes is likely attributable to its advanced capability to discriminate soft tissue characteristics, offering high-resolution visualization that facilitates identification even in challenging anatomical locations. However, the false-positive rate may also reflect limitations inherent to pediatric imaging, such as motion artifacts, overlap with adjacent bowel or lymphatic tissue, and the inherent difficulty in distinguishing regressed or atrophic gonadal remnants from viable testicular tissue on imaging alone (14,16).

This study's strengths include its robust prospective design, the use of a well-defined cohort with standardized imaging protocols, and the application of laparoscopy as the definitive reference standard, all of which contribute to the reliability and clinical applicability of the findings. The sample size of 292 patients enhances the statistical power and supports the generalizability of the results within similar clinical settings. Nonetheless, several limitations warrant acknowledgment. The reported inconsistency between group mean ages and the defined age ranges suggests potential data labeling or reporting errors, which, although not affecting the primary outcome, may limit subgroup analyses and external validity. The study was conducted at a single tertiary care institution, possibly introducing referral bias and limiting generalizability to broader or more diverse populations. Additionally, the absence of assessment of inter-observer variability in MRI interpretation is a potential limitation, given the subjective component inherent to radiological assessment.

Future research should aim to address these limitations by conducting multicenter studies with larger, more diverse populations and by standardizing imaging protocols across sites. Incorporating blinded, multi-reader assessments would further strengthen the evidence base and enhance the reliability of DW-MRI interpretation. Exploration of advanced MRI techniques or the integration of artificial intelligence-driven image analysis may also help reduce false positives and improve specificity. Furthermore, combining DW-MRI with other non-invasive modalities such as high-resolution ultrasound may create synergistic diagnostic pathways that could optimize sensitivity and specificity while minimizing invasiveness (17,18).

In summary, this study provides strong evidence that DW-MRI is a highly sensitive and reliable tool for the exclusion of undescended testes in pediatric patients. However, its moderate specificity and agreement with laparoscopy underscore the necessity of surgical confirmation for positive findings. The integration of DW-MRI into clinical practice should be considered within a complementary framework, augmenting but not replacing the current gold standard. These findings contribute meaningfully to the evolving diagnostic paradigm of cryptorchidism and highlight the need for continued innovation and validation in non-invasive diagnostic imaging (15,17).

CONCLUSION

This study demonstrates that diffusion-weighted magnetic resonance imaging (DW-MRI) possesses high sensitivity and negative predictive value for the detection of cryptorchidism, supporting its role as a reliable non-invasive modality for ruling out undescended testes in pediatric patients when compared to the gold standard of laparoscopy. However, due to its moderate specificity and positive predictive value, DW-MRI should be interpreted as a complementary diagnostic tool rather than a replacement for surgical confirmation. Clinically, the integration of DW-MRI may reduce unnecessary invasive procedures and optimize patient management, but positive imaging findings must be corroborated by laparoscopy to ensure diagnostic accuracy. For future research, multicenter studies with standardized imaging protocols and advanced analytic techniques are recommended to further refine the diagnostic utility of DW-MRI and enhance its role in the evaluation and management of cryptorchidism in pediatric healthcare.

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