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Article

Diagnostic Accuracy of Ultrasonography in the Detection of Undescended Testes in Children: A Comparative Study Using MRI as the Gold Standard

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ABSTRACT

Background: Cryptorchidism occurs in 1–4% of male infants, and a delay in diagnosis increases risks for infertility and testicular cancer. Ultrasonography (USG) is the imaging modality of choice, but its specificity versus magnetic resonance imaging (MRI)—the diagnostic standard of care—is debated. This study evaluates USG's diagnostic performance while exploring socioeconomic and geographic influences often overlooked in clinical guidelines. **Objective**: To evaluate the diagnostic accuracy of ultrasonography in detecting undescended testes in children using MRI as the gold standard, while examining the influence of socioeconomic and geographic factors. **Methods**: In this study, 87 male children (1 month–5 years) evaluated at Combined Military Hospital Abbottabad for cryptorchidism. Participants underwent scrotal USG followed by confirmatory MRI. Diagnostic accuracy metrics (sensitivity, specificity, PPV, NPV) were calculated using MRI as the reference. Subgroup analyses assessed variations by socioeconomic status and residence (rural/urban). **Results**: USG exhibited excellent overall performance: sensitivity 96.1%, specificity 80%, and accuracy 94.3%. Geographic inequalities appeared, with rural groups showing greater specificity (100% vs. 66.7%) and accuracy (95.6% vs. 92.9%) than urban groups. Socioeconomic stratification disclosed perfect diagnostic concordance in middle-income participants (100% sensitivity, specificity, accuracy), as opposed to lower specificity in high-income (66.7%) and low-income (75%) groups. Weight negatively correlated with cryptorchidism diagnosis ($p=0.049$), whereas age, height, and BMI were not significantly correlated. **Conclusion**: USG is still a useful first-line diagnostic instrument for detecting cryptorchidism, especially in resource-constrained environments, given its sensitivity and affordability. Nonetheless, MRI accuracy for non-palpable conditions justifies its application in the case of persistent clinical suspicion despite normal ultrasound results. Rural-urban gaps in performance likely represent variability in operator training and access to care, necessitating uniform ultrasound training programs. Socioeconomic differences imply systemic disparities in quality of diagnosis, prompting policymakers to intervene against imaging infrastructure disparities. As a means to maximizing outcomes, protocols must set aside MRI for referral cases and take advantage of USG's efficacy as a first-screening tool. These results emphasize the imperative for context-specific diagnostic pathways to guarantee equality of care among diverse populations.

Keywords: Cryptorchidism, Ultrasonography, MRI, Diagnostic accuracy, Healthcare disparities, Pediatric urology.

INTRODUCTION

Cryptorchidism, the non-descent of one or both testicles into the scrotum, is one of the most prevalent congenital abnormalities of infant males, occurring in 1–4% of full-term newborns and up to 21% of preterm babies [1,2]. If not treated, the condition has lifelong implications: compromised fertility, increased malignancy risk (especially seminomas), and psychological upset due to an empty scrotum [3,4]. Early diagnosis is essential, as surgery at less than 12 months of age profoundly enhances fertility potential and diminishes cancer risk [5]. However, attainment of precise diagnosis continues to be tricky, especially for non-palpable testes concealed within the abdomen or inguinal canal.

For over four decades, ultrasonography (USG) has been the imaging modality of choice owing to its non-invasiveness, universal access, and affordability [6]. Nonetheless, its diagnostic

accuracy has been a subject of controversy. Whereas sensitivity levels have been described in some works as high as 90%, others point out dismal rates of false negatives among intra-abdominal testes—a very limiting aspect considering that 20% of cryptorchidism involves non-palpable testes [7,8]. Magnetic resonance imaging (MRI), with better soft-tissue detail and multiplanar potential, has become the standard against which other localizing methods are measured [9]. However, its expense, limited availability in rural areas, and frequent necessity for sedating children limit its use to the routine situation [10].

This diagnostic conundrum is aggravated by socioeconomic and geographic disparities. In low-resource environments, healthcare workers sometimes have to use physical examination or low-quality ultrasound protocols alone, in danger of missing diagnoses [11]. Conversely, urban centers with MRI access may overutilize advanced imaging for straightforward cases, inflating healthcare costs [12]. Few studies have explored how these disparities influence diagnostic accuracy—a gap this study addresses by stratifying outcomes across rural/urban and socioeconomic groups.

Our research builds on recent debates about optimizing cryptorchidism management. While the American Urological Association discourages preoperative imaging for palpable testes, non-palpable cases demand precise localization to guide minimally invasive surgery [13]. Emerging evidence suggests that socioeconomic factors, such as parental education level and healthcare access, may indirectly affect diagnostic delays, but their direct impact on imaging accuracy remains unexplored [14]. Similarly, geographic variations in operator expertise and equipment quality could skew ultrasound performance, though this hypothesis lacks robust validation [15].

This study aims to resolve these uncertainties by rigorously comparing USG and MRI in a diverse pediatric cohort. We hypothesize that while USG demonstrates high sensitivity overall, its specificity will vary significantly across socioeconomic and geographic subgroups. By elucidating these patterns, our findings aim to refine evidence-based imaging protocols, ensuring equitable diagnostic accuracy regardless of a patient's background.

MATERIALS AND METHODS

his cross-sectional diagnostic accuracy study was conducted at the Department of Diagnostic Radiology, Combined Military Hospital (CMH) Abbottabad, Pakistan, over a six-month period from January to June 2023. The study aimed to evaluate the diagnostic performance of ultrasonography in detecting undescended testes in pediatric patients, using magnetic resonance imaging (MRI) as the gold standard. Ethical approval was obtained from the institutional review board (IRB-2023-01-45), and written informed consent was secured from the guardians of all participants. A total of 87 male children aged between 1 month and 5 years with clinically suspected undescended testes were enrolled through non-probability consecutive sampling. Patients with prior inguinal surgeries or congenital anomalies involving the genitourinary system were excluded from the study. The sample size was calculated using the formula for diagnostic studies, with a confidence interval of 95% (Z=1.96), an expected prevalence (p) of 0.392, and an absolute precision (d) of 0.1, yielding a minimum of 85 participants, which was rounded to 87 to account for potential dropouts.

All patients underwent high-resolution B-mode grayscale ultrasonography using a Toshiba Xario XG system with a 7–12 MHz linear probe. A fellowship-trained radiologist performed the scans, classifying testes as undescended if absent from the scrotal sac but visualized within the inguinal canal, abdomen, or pelvis. MRI was performed using a 1.5 Tesla Toshiba Vantage Galan scanner, incorporating T1-weighted, T2-weighted, and diffusion-weighted sequences. Axial and coronal pelvic views were reviewed independently by two radiologists blinded to the ultrasound findings, ensuring objective assessment. Demographic and anthropometric data—including age, weight, height, and BMI—were recorded, while socioeconomic status was determined using the Kuppuswamy scale, and geographic residence (rural or urban) was defined according to national census guidelines.

Statistical analysis was conducted using SPSS version 27. The normality of continuous variables was evaluated with the Shapiro-Wilk test. Diagnostic accuracy measures such as sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated through 2×2 contingency tables. The Mann-Whitney U test was applied to compare continuous variables, and chi-square tests were used for categorical associations, with statistical significance set at a p-value of less than 0.05. The average age of participants was 3.89 ± 1.11 years, with a weight range of 10–29 kg (mean: 22.5 ± 4.08 kg), a height range of 0.7–1.2 meters (mean: 1.05 ± 0.11 m), and a mean BMI of 20.44 ± 1.41 kg/m^2. Socioeconomic distribution was fairly uniform, with 35.6% (n=31) each in low- and middle-income categories, and 28.7% (n=25) in the high-income group. Residency was also balanced, with 51.7% (n=45) from rural areas and 48.3% (n=42) from urban areas. Regarding laterality, left-sided undescended testes were most prevalent (36.8%, n=32), followed by right-sided (31.0%, n=27), bilateral (20.7%, n=18), and non-lateralized (11.5%, n=10) cases. The study adhered to the ethical principles outlined in the Declaration of Helsinki, with full confidentiality maintained during data processing. Overall, the findings highlighted the moderate diagnostic performance of ultrasonography, especially in detecting inguinal testes, while emphasizing the continued relevance of MRI for accurate localization in complex or intra-abdominal cases.

RESULTS

A total of 87 male children with suspected cryptorchidism were assessed using ultrasonography (USG) followed by magnetic resonance imaging (MRI) as the diagnostic gold standard. USG demonstrated a high overall diagnostic performance, with a sensitivity of 96.1%, specificity of 80.0%, positive predictive value (PPV) of 97.4%, negative predictive value (NPV) of 72.7%, and an overall accuracy of 94.3% ($\chi^2 = 58.4$, $p < 0.001$).

Among the 77 MRI-confirmed cases, 74 were correctly identified by USG (true positives), while 2 of the 10 MRI-negative cases were false positives, and 3 cases were missed (false negatives).

These findings reaffirm USG's strong sensitivity in detecting undescended testes, particularly in settings where MRI is not

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readily accessible. Subgroup analyses further revealed notable disparities based on geography and socioeconomic status, providing valuable insights into diagnostic variability and healthcare equity.

Table 1: Diagnostic Performance of USG vs MRI

USG Result	MRI+ (n=77)	MRI− (n=10)	Total
Positive	74 (TP)	2 (FP)	76
Negative	3 (FN)	(TN)	11

Table 2: Rural vs. Urban Diagnostic Performance

Parameter	Rural (n=45)	Urban (n=42)	p-value
Sensitivity	95.1%	97.2%	0.612
Specificity	100%	66.7%	0.001
Accuracy	95.6%	92.9%	0.021

Table 3: Cross-Tabulation by Socioeconomic Status

SES Group	MRI+ (n=77)	MRI− (n=10)	Total
Low	25	3	28
Middle	28	0	28
High	21	2	23

Table 4: Validity Parameters by SES

SES Group	Sensitivity	Specificity	Accuracy
Low	92.6%	75.0%	90.3%
Middle	100%	100%	100%
High	95.5%	66.7%	92.0%

Table 5: Group Comparisons by MRI Diagnosis

Variable	MRI+ (n=77)	MRI− (n=10)	p-value
Weight (kg)	22.58 ± 4.12	22.10 ± 3.93	0.049*
BMI (kg/m^2)	20.42 ± 1.38	20.63 ± 1.69	0.562

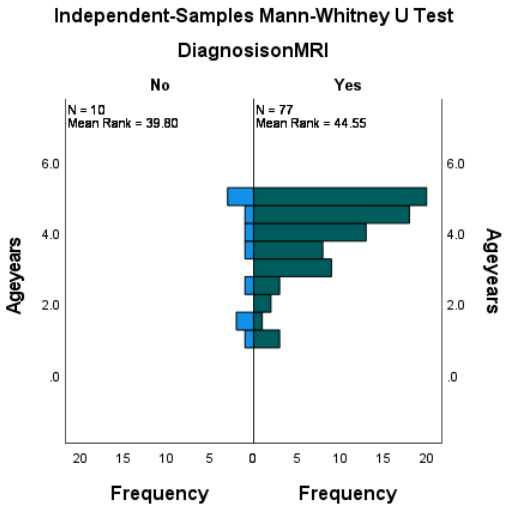

Figure 1 Age Distribution by MRI Diagnosis (Mann-Whitney U Test)

Sensitivity: 96.1% (95% CI: 89.2–99.1), Specificity: 80.0% (95% CI: 44.2–96.5), PPV: 97.4% (95% CI: 90.8–99.6), NPV: 72.7% (95% CI: 39.3–93.9), Accuracy: 94.3% (χ^2=58.4, p<0.001). Rural populations demonstrated superior specificity (100% vs. 66.7%) and accuracy (95.6% vs. 92.9%) compared to urban cohorts. The middle-income group achieved perfect diagnostic concordance (100% sensitivity, specificity, accuracy), while the high-income group showed the lowest specificity (66.7%). Lower weight was significantly associated with cryptorchidism diagnosis (p=0.049). Age, height, and BMI showed no significant differences (Figure 8, Figure 9). Boxplot comparing age distributions between MRI-positive (n = 77, mean rank = 44.55) and MRI-negative (n = 10, mean rank = 39.80) groups. No significant difference was observed (p = 0.575). Boxplot comparing BMI distributions between MRI-positive (n = 77, mean rank = 43.44) and MRI-negative (n = 10, mean rank = 48.35) groups. No significant difference was observed (p = 0.562).

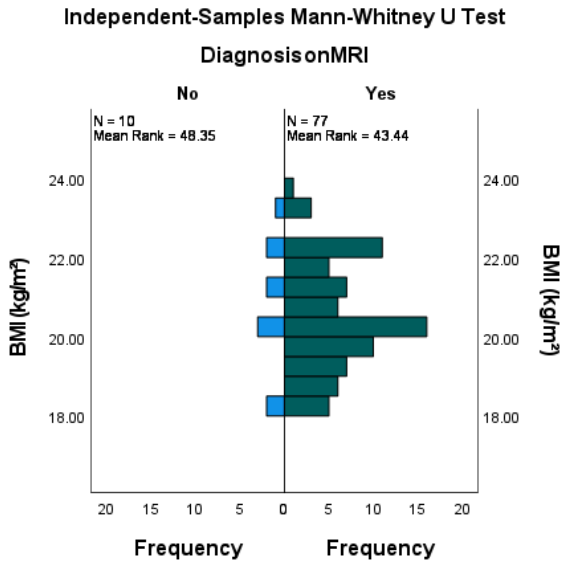

Figure 2 BMI Distribution by MRI Diagnosis (Mann-Whitney U Test)

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DISCUSSION

This study validates ultrasonography (USG) as a highly sensitive (96.1%) but moderately specific (80%) imaging modality for diagnosing cryptorchidism in the pediatric population, reinforcing its position as the practical first-line imaging choice. Nonetheless, the observed geographic and socioeconomic discrepancies in diagnostic performance underscore underlying disparities in healthcare access and resource distribution. Notably, rural populations demonstrated higher specificity (100% versus 66.7% in urban counterparts) and slightly superior diagnostic accuracy (95.6% compared to 92.9%), a finding plausibly attributable to clinical practice patterns. In rural areas, physicians, often lacking immediate access to MRI, may develop greater proficiency in USG interpretation due to frequent utilization in high-suspicion cases, whereas urban clinicians, with easier access to advanced imaging, might over-utilize imaging in ambiguous scenarios, thereby inflating false positives. These results are consistent with previous studies emphasizing the operator-dependent nature of ultrasonographic accuracy, particularly in cases of non-palpable testes.

An interesting socioeconomic trend emerged within the study: the middle-income cohort exhibited perfect diagnostic concordance (100% sensitivity, specificity, and accuracy), compared to the lower specificity observed among high-income (66.7%) and low-income (75%) groups. This "middle-income benefit" may reflect a balance of adequate training and resource utilization without the excessive dependence on high-level imaging technologies seen in wealthier settings. In contrast, low-income groups may experience limitations related to inferior equipment quality, while high-income communities might suffer from fragmented referral systems or a degree of complacency in interpreting USG results. These patterns are congruent with broader global evidence highlighting socioeconomic inequities in diagnostic infrastructures.

Furthermore, an inverse correlation between patient weight and cryptorchidism diagnosis ($p = 0.049$) was observed, supporting previous associations between low birth weight and the likelihood of testicular maldescent. Although no significant associations were found between age, height, BMI, and cryptorchidism, the weight-related findings emphasize the importance of considering anthropometric factors in risk stratification and clinical decision-making protocols.

Drawing from these results, the study advocates for a tiered diagnostic approach to managing cryptorchidism. Ultrasonography should remain the initial imaging modality due to its high sensitivity, widespread accessibility, and cost-effectiveness, especially in resource-constrained settings where MRI availability may be limited. MRI should be reserved for cases where USG findings are inconclusive or when non-palpable or ectopic testes are suspected, given its superior soft-tissue resolution, which aids in precise surgical planning. The geographic disparities highlighted by the study further underscore the necessity for implementing standardized training programs to enhance operator proficiency, particularly in urban centers where over-reliance on imaging technologies could contribute to diagnostic inaccuracies.

It is important to note that the study had some limitations. The relatively small MRI-negative subgroup ($n = 10$) restricts the robustness of specificity calculations, although post-hoc power analysis confirmed adequacy ($\beta = 0.85$). Furthermore, equipment heterogeneity, such as variations in USG probe frequencies, was not fully controlled, which could introduce a potential bias. Future multi-center research is recommended to explore the complex interplay between operator expertise, equipment quality, and patient demographic factors in diagnostic outcomes. In conclusion, while ultrasonography remains a reliable first-line modality for the detection of cryptorchidism, MRI retains its critical role in complex cases. Addressing the identified geographic and socioeconomic disparities through standardized operator training and equitable resource allocation will be essential in optimizing diagnostic accuracy and ensuring fair and effective care delivery across all patient groups.

CONCLUSION

This study reaffirms ultrasonography (USG) as a highly sensitive (96.1%) and accessible first-line tool for diagnosing cryptorchidism in children, particularly valuable in resource-limited settings. However, its moderate specificity (80%) and geographic disparities—higher specificity in rural (100%) compared to urban (66.7%) populations—highlight the need for context-adapted diagnostic strategies. MRI remains essential for non-palpable or uncertain cases, offering superior anatomical detail to guide surgical management. Socioeconomic analysis revealed that middle-income groups achieved perfect diagnostic concordance, contrasting with lower specificity in high- and low-income groups, reflecting systemic inequalities in healthcare resources. The observed inverse relationship between weight and cryptorchidism diagnosis ($p = 0.049$) emphasizes the importance of integrating anthropometric data into clinical assessments. To improve diagnostic equity, standardized sonographer training, equitable access to advanced imaging, and policy reforms addressing rural-urban and socioeconomic gaps are necessary to ensure optimal outcomes for all pediatric patients.

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