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Diagnostic Efficacy of Magnetic Resonance Imaging versus Ultrasound in the Evaluation of Scrotal Lesions: A Prospective Cross-sectional Study

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A B S T R A C T

Objective*:** This study aims to evaluate the diagnostic efficacy of Magnetic Resonance Imaging (MRI) in assessing scrotal lesions, with a focus on differentiating between benign and malignant conditions. The limitations of ultrasound in some scrotal pathologies underscore the need for an advanced modality like MRI to improve diagnostic accuracy.Methods*:** A prospective cross-sectional study was conducted on 102 male patients presenting with symptoms of scrotal lesions. All participants underwent both ultrasound and MRI evaluations, with results compared against histopathological findings. Imaging sequences included T1-weighted, T2-weighted, and diffusion-weighted imaging (DWI). Statistical analyses included sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and ROC curves to assess MRI's diagnostic accuracy.***Results*:** MRI showed higher diagnostic accuracy (96.1%) compared to ultrasound (91.2%) in identifying scrotal lesions. Specifically, MRI demonstrated sensitivity and specificity rates of 94.1% and 96.5%, respectively, while ultrasound showed 88.2% and 91.8%. ROC analysis further established MRI's superior diagnostic performance in distinguishing between torsion, epididymo-orchitis, and malignancies.***Conclusion*:** MRI is a valuable diagnostic tool for scrotal lesions, particularly in cases where ultrasound results are inconclusive. Its high sensitivity and specificity make MRI a recommended modality for comprehensive scrotal lesion evaluation.

Keywords: MRI, scrotal lesions, ultrasound, diagnostic accuracy, diffusion-weighted imaging.

INTRODUCTION

Scrotal pathologies are a common clinical concern in men, and effective imaging plays a critical role in assessing these conditions. Initial evaluation of scrotal lesions traditionally relies on ultrasound (US), particularly B-mode and color Doppler imaging, due to its accessibility, low cost, and non-ionizing nature. Ultrasound offers high sensitivity for detecting a range of scrotal pathologies, including inflammation, trauma, and tumors. However, it is limited by its operator-dependent nature, small field of view, and reduced ability to provide detailed tissue characterization [1].

In some cases, conditions such as partial torsion, torsion-detorsion syndrome, or acute epididymo-orchitis may yield ambiguous ultrasound findings, risking misdiagnoses that could lead to inappropriate surgical interventions [2]. Moreover, distinguishing between benign and malignant lesions can sometimes be challenging with ultrasound alone. For example, subtle lesions like minor tears in the tunica albuginea or early neoplastic changes may not be fully appreciated on US imaging [3]. In such cases, a more advanced imaging modality like Magnetic Resonance Imaging (MRI) is necessary for a precise diagnosis [4].

MRI of the scrotum has emerged as a valuable diagnostic tool, providing high-resolution, multi-planar images with superior soft tissue contrast. MRI is less operator-dependent, has a larger field of view, and, critically, it does not involve ionizing radiation, making it a safe option for repeat imaging when necessary [5]. Additionally, MRI's ability to perform diffusion-weighted imaging (DWI) allows for functional assessment by measuring water molecule movement within tissues, which can be indicative of cellularity. DWI is particularly useful in detecting malignancies due to their characteristic restricted diffusion [6].

Studies have shown that MRI can play a pivotal role in differentiating various scrotal pathologies. It has proven especially useful in cases of suspected testicular torsion, where it can reveal twisted cord structures with high specificity [7]. In cases of malignancy, MRI can also help identify the tumor's composition, allowing for the differentiation of seminomatous from non-seminomatous germ cell tumors, which is crucial for prognosis and treatment planning [8]. Notably, a study by Tsili*et al*., demonstrated that the apparent diffusion coefficient (ADC) values in testicular tissue can help distinguish normal tissue from neoplastic changes, further underscoring the role of MRI in scrotal lesion assessment [9].

However, despite the promising attributes of MRI, few studies have systematically examined its diagnostic accuracy compared to ultrasound across a broad range of scrotal pathologies. Thus, this study aims to address this gap by evaluating the diagnostic utility of MRI in a range of scrotal lesions, comparing its effectiveness directly with ultrasound and histopathology findings. By doing so, we aim to define MRI's role in routine clinical practice, especially in cases where ultrasound results are inconclusive or suggest a need for further evaluation [10].

Aims and Objectives

The primary aim of this study was to evaluate the diagnostic accuracy and clinical utility of Magnetic Resonance Imaging (MRI) in detecting, characterizing, and differentiating scrotal lesions, especially in cases where ultrasound findings were inconclusive or insufficient. The study aimed to assess MRI's diagnostic performance compared to ultrasound and its alignment with histopathological findings, specifically for distinguishing benign from malignant conditions in scrotal pathologies. Secondary objectives included determining the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of MRI and ultrasound in the diagnosis of various scrotal pathologies, and evaluating the efficacy of specific MRI sequences, including T1-weighted, T2-weighted, and diffusion-weighted imaging (DWI), in enhancing diagnostic accuracy for scrotal lesions.

Materials and Methods

Study Design and Setting

This study was designed as a prospective cross-sectional study, conducted in the Department of Radiodiagnosis at Stanley Medical College, Chennai. The study was carried out over a period of 20 months, from April 2021 to November 2022, allowing ample time to assess and compare the diagnostic findings of MRI and ultrasound in scrotal pathology cases.

Study Population

The study population consisted of male patients presenting with clinical signs and symptoms indicative of scrotal lesions. A total of 102 patients were enrolled in the study, selected through a consecutive sampling method. All patients were referred to the radiodiagnosis department for imaging studies after presenting with a variety of scrotal symptoms, including pain, swelling, and palpable masses, which necessitated further evaluation.

Inclusion Criteria

The study included male patients of all age groups who exhibited clinical features of scrotal lesions and had been referred for imaging. The broad inclusion criteria were selected to ensure a comprehensive assessment of MRI's diagnostic potential across a diverse patient group. Importantly, since MRI is a non-ionizing imaging modality, age was not a limiting factor in this study.

Exclusion Criteria

Exclusion criteria were strictly enforced to ensure the safety of participants and the integrity of the imaging data. Patients with contraindications to MRI were excluded, including those with implanted devices such as internal cardiac pacemakers, implantable cardiac defibrillators, cochlear implants, and ocular implants, as well as those with aneurysm clips and other MR-incompatible metallic implants. Patients with known allergies to gadolinium-based contrast media, used for enhanced MRI sequences, were also excluded from the study to avoid adverse reactions. Additionally, patients with claustrophobia who could not tolerate the MRI environment and those who declined to give informed consent were not included. Any patients lost to follow-up after initial imaging were removed from the study to maintain data completeness.

Sample Size Determination

The required sample size was calculated based on an expected sensitivity of 98% for MRI in diagnosing malignant scrotal and testicular lesions, derived from prior studies. Using the formula n=Z2·p·(1−p)/d2n = Z^2 \cdot p \cdot (1-p) / d^2n=Z2·p·(1−p)/d2, where ZZZ represents the standard normal variate for a 95% confidence level (1.96), ppp is the sensitivity of MRI (98%), and ddd is the desired absolute precision (3%), the calculated minimum sample size was 84. To account for potential non-response or dropouts, an additional 10% was added, resulting in a final sample size requirement of approximately 100 patients, which was rounded to 102 participants for this study.

Imaging Protocols and Procedure

All patients underwent an initial baseline ultrasound examination of the scrotum, which included Doppler imaging. Ultrasound examinations were performed using a high-resolution sonographic unit with a 7-15 MHz linear array transducer for scrotal imaging and a 3.5-5 MHz convex transducer for abdominal imaging when needed, particularly in cases involving undescended testes or suspected para-aortic lymph node involvement. Ultrasound images were assessed by a radiologist with at least five years of experience in scrotal imaging.

Following ultrasound, MRI was conducted using a 1.5-T clinical MRI system (Siemens Amira, Siemens Medical Solutions, Erlangen, Germany) with a high-resolution surface coil positioned toward the scrotum for optimal signal detection. Patients were placed in a supine position, with the scrotum supported to minimize movement and ensure consistent coil placement. MRI sequences included axial, coronal, and sagittal T1-weighted spin-echo sequences (TR/TE, 500-650/13-15), T2-weighted fast spin-echo sequences (4000/100-120) with a slice thickness of 3-4 mm and a 0.5-mm gap, and diffusion-weighted imaging (DWI) sequences with b-values of 0, 400, and 800 s/mm². In cases of hyperintense lesions on T1-weighted images, T1-weighted sequences with fat saturation were performed to improve lesion characterization. Gadolinium contrast (0.2 mmol/kg of gadodiamide) was administered intravenously when necessary to enhance visualization, particularly in suspected neoplastic or vascular lesions.

Image Interpretation

Ultrasound images were reviewed by a radiologist with at least five years of experience, and MRI interpretations were conducted independently by two radiologists specializing in uroradiology, each with over five years of MRI experience. To ensure objectivity, the radiologists were blinded to each other's findings; the MRI radiologist was not informed of the ultrasound findings, and vice versa. In cases where the initial MRI interpretation differed between the two radiologists, a consensus was reached after joint discussion. Imaging findings from both modalities were compared with clinical details and histopathology reports, where available. For patients managed conservatively, follow-up imaging was conducted to verify outcomes and monitor disease progression.

Statistical Analysis

The data were analyzed using IBM SPSS Statistics for Windows, Version 23.0 (Armonk, NY: IBM Corp). Descriptive statistics, including frequency and percentage analysis, were used for categorical variables, while mean and standard deviation (SD) were calculated for continuous variables. Paired sample t-tests were conducted to assess the significance of differences between paired groups, while one-way ANOVA with Tukey's post-hoc test was used for multivariate comparisons. Receiver Operating Characteristics (ROC) curves were generated to compare the diagnostic efficacy of ultrasound and MRI for predicting histopathology outcomes. Sensitivity, specificity, PPV, NPV, and overall accuracy were calculated, with statistical significance set at a p-value of 0.05.

RESULTS

The study evaluated 102 male patients who presented with various scrotal lesions, utilizing both ultrasound and MRI for diagnostic purposes. The patients spanned all age groups, with the age distribution revealing a notable concentration in the middle-aged bracket. Specifically, the age group of 41-50 years had the highest prevalence of scrotal pathologies, accounting for 25.5% of the total cases. This was followed by the over 60 years age group, which comprised 19.6% of the study population. The least affected were those under 10 years, making up only 5.9% of the cases.

In terms of laterality, the right side was more frequently affected, with 53 cases (52.0%) of the lesions occurring on the right, 45 cases (44.1%) on the left, and a minimal 4 cases (3.9%) presenting bilaterally. This distribution underscores a slight predilection for right-sided scrotal lesions within the studied cohort.

The quality of imaging significantly impacts the interpretability of diagnostic results, and in this study, MRI demonstrated a high degree of clarity. Out of the total images reviewed, 91.2% were classified as of good quality, facilitating precise assessments. Only 8.8% of MRI scans were rated as of intermediate quality, indicating occasional challenges in imaging interpretation, yet no images fell into the poor quality category.

The types of lesions evaluated showed a diverse range of scrotal conditions. Intratesticular lesions were identified in 27.5% of the cases, making them a common finding. Lesions in other scrotal structures were also noted, with 20.6% in the tunica vaginalis sac, 13.7% in the spermatic cord, and 11.8% in the epididymis. Additionally, 20.6% of the cases involved both testicular and extratesticular regions, illustrating the complex nature of some scrotal pathologies.

Diagnostic accuracy was a key outcome of this study, comparing the efficacy of ultrasound versus MRI. Overall, MRI outperformed ultrasound in diagnostic accuracy, with a superior sensitivity of 94.1% compared to 88.2% for ultrasound. MRI also showcased higher specificity at 96.5%, significantly better than the 91.8% specificity observed with ultrasound. These metrics underline MRI's robustness in discerning the nature of scrotal lesions with high precision. Moreover, the positive predictive value (PPV) for MRI was 84.2%, and the negative predictive value (NPV) stood at 98.8%, reflecting its reliability in diagnosing scrotal conditions. The overall accuracy of MRI reached 96.1%, demonstrating its superior diagnostic capabilities compared to ultrasound, which held an overall accuracy of 91.2%.

These findings emphasize the importance of advanced imaging techniques like MRI in the evaluation of scrotal lesions, particularly when ultrasound results are ambiguous or inconclusive. MRI not only provides greater detail and clarity in imaging but also offers a higher probability of accurate diagnosis, which is crucial for effective patient management and treatment planning.

Table 1: Age Distribution of Patients with Scrotal Pathologies

Age Group (years)	Frequency (%)
<10	6 (5.9%)
11-20	14 (13.7%)
21-30	15 (14.7%)
31-40	12 (11.8%)
41-50	26 (25.5%)
51-60	9 (8.8%)
>60	20 (19.6%)

Table 2: Laterality Distribution of Scrotal Lesions

Laterality	Frequency (%)
Right	53 (52.0%)
Left	45 (44.1%)
Bilateral	4 (3.9%)

Table 3: Image Quality Assessment of MRI in Scrotal Pathologies

Image Quality	Frequency (%)
Good	93 (91.2%)
Intermediate	9 (8.8%)

Table 4: Distribution of Scrotal Lesion Types

Location	Frequency (%)
Intratesticular	28 (27.5%)
Epididymis	12 (11.8%)
Spermatic Cord	14 (13.7%)
Tunica Vaginalis Sac	21 (20.6%)
Scrotal Wall	6 (5.9%)
Both Testicular &Extratesticular	21 (20.6%)

Table 5: Comparative Diagnostic Accuracy of Ultrasound and MRI

Modality	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Ultrasound	88.2	91.8	68.2	97.5	91.2
MRI	94.1	96.5	84.2	98.8	96.1

DISCUSSION

The findings of this study highlight the enhanced diagnostic capabilities of MRI compared to ultrasound in the evaluation of scrotal lesions. The superior sensitivity (94.1%) and specificity (96.5%) of MRI observed in this study align with previous research that has emphasized MRI's capacity for detailed soft tissue contrast and higher diagnostic accuracy [11]. Unlike ultrasound, which had lower sensitivity (88.2%) and specificity (91.8%), MRI demonstrated a robust ability to differentiate between various scrotal pathologies, thus minimizing the risk of misdiagnosis.

MRI's advantage is particularly evident in its high positive predictive value (84.2%) and negative predictive value (98.8%), suggesting its efficacy in correctly identifying the presence and absence of disease. These findings are consistent with those reported by Smith *et al*., who noted that MRI's detailed imaging capabilities are crucial in clinical settings where ultrasound results are inconclusive or when the clinical examination raises suspicion of complex or malignant lesions [12].

Furthermore, the study supports the utility of MRI in managing ambiguous cases or where ultrasound has limitations due to its operator-dependent nature. The ability of MRI to provide detailed imaging without the interference of operator variability significantly reduces the likelihood of diagnostic errors. This aspect is crucial in medical practice, as noted by Johnson and colleagues, who discussed the impact of imaging quality on treatment decisions and outcomes in scrotal pathology [13].

In addition, MRI's role in distinguishing benign from malignant lesions has important implications for patient management. The accuracy of MRI in identifying malignancies, as reflected by its higher diagnostic metrics, supports its use as a complementary tool to ultrasound, especially in high-risk patients or those with equivocal ultrasound findings [14]. This study, therefore, reinforces the recommendation by Lee *et al*., for incorporating MRI into the diagnostic pathway for scrotal lesions, particularly when other modalities are insufficient [15].

CONCLUSION

This study conclusively demonstrates that Magnetic Resonance Imaging (MRI) holds significant advantages over ultrasound in the diagnosis of scrotal lesions, with higher sensitivity, specificity, and overall diagnostic accuracy. The ability of MRI to deliver high-quality images and reliable diagnostic data supports its role as an essential imaging modality in the evaluation of scrotal pathologies. Given its higher predictive values and accuracy, MRI not only enhances diagnostic confidence but also aids in the effective management and treatment planning of scrotal conditions. It is recommended that MRI be considered a crucial diagnostic tool, particularly in complex cases where ultrasound is inconclusive or when precise lesion characterization is necessary for optimal patient care.

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