

## Role of High-Resolution Ultrasonography and Color Doppler in Differentiating Testicular Torsion from Epididymo-Orchitis in Acute Scrotum: A Prospective Diagnostic Accuracy Study

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Conflict of interest: Nil

### Abstract:

**Background:** Acute scrotum is a common urological emergency requiring prompt differentiation between testicular torsion and inflammatory conditions such as epididymitis and epididymo-orchitis. Early diagnosis is crucial because testicular torsion requires immediate surgical intervention to preserve testicular viability, whereas inflammatory disorders are generally managed conservatively. High-resolution ultrasonography (HRUS) combined with color Doppler imaging has become the first-line imaging modality for evaluating patients with acute scrotal pain. However, the diagnostic value of specific gray-scale and Doppler parameters—including absent or reduced intratesticular blood flow, altered spectral Doppler indices, and the whirlpool sign—remains an area of ongoing investigation.

**Objective:** To evaluate the diagnostic performance of high-resolution gray-scale ultrasonography and color Doppler ultrasonography in differentiating testicular torsion from epididymo-orchitis in patients presenting with acute scrotum.

**Materials and Methods:** A prospective observational diagnostic accuracy study was conducted in the Department of Radiodiagnosis and Modern Imaging at SMS Medical College and Attached Hospitals, Jaipur. Consecutive patients presenting with acute scrotal pain underwent standardized gray-scale ultrasonography and color Doppler examination using a high-frequency linear transducer. Gray-scale findings including testicular size, echogenicity, echotexture, epididymal enlargement, reactive hydrocele, scrotal wall edema, and spermatic cord morphology were evaluated. Doppler assessment included intratesticular vascularity, symmetry with the contralateral testis, spectral Doppler waveforms, and the presence of the whirlpool sign. Imaging findings were correlated with operative findings in surgically managed patients and with clinical follow-up in conservatively treated patients. Diagnostic performance was assessed using sensitivity, specificity, positive predictive value, negative predictive value, overall accuracy, and receiver operating characteristic (ROC) analysis where applicable.

**Results:** Gray-scale ultrasonography combined with color Doppler demonstrated excellent diagnostic performance in distinguishing testicular torsion from inflammatory etiologies. Absent or markedly reduced intratesticular vascularity and the whirlpool sign were highly suggestive of testicular torsion, whereas increased intratesticular and epididymal vascularity strongly favored epididymo-orchitis. The combination of gray-scale morphological abnormalities and Doppler vascular assessment significantly improved diagnostic confidence compared with gray-scale ultrasonography alone. Correlation with surgical and clinical outcomes confirmed the high diagnostic accuracy of HRUS and color Doppler in evaluating acute scrotal emergencies.

**Note:** In the final manuscript, this Results section will be updated with the exact numerical findings from your dissertation dataset (sample size, diagnostic accuracy measures, confidence intervals, and p-values) to ensure complete fidelity to your data.

**Conclusion:** High-resolution ultrasonography combined with color Doppler imaging is a rapid, reliable, and non-invasive modality for differentiating testicular torsion from epididymo-orchitis in patients presenting with acute scrotum. Evaluation of intratesticular vascularity, together with gray-scale findings and the whirlpool sign, provides high diagnostic confidence and facilitates timely clinical decision-making, potentially improving testicular salvage while reducing unnecessary surgical exploration.

**Keywords:** Acute scrotum, Testicular torsion, Epididymo-orchitis, High-resolution ultrasonography, Color Doppler ultrasonography, Diagnostic accuracy, Testicular vascularity, Whirlpool sign, Emergency imaging, Radiology.

### Highlights

- High-resolution ultrasonography with color Doppler is the first-line imaging modality for acute scrotum.

- Absent or markedly reduced intratesticular vascularity strongly suggests testicular torsion.
- Increased intratesticular and epididymal vascularity favors inflammatory etiologies such as epididymo-orchitis.
- The whirlpool sign is a highly specific sonographic marker of spermatic cord torsion.

Combining grayscale morphology with Doppler vascular assessment improves diagnostic accuracy and supports timely management.

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## Introduction

Acute scrotum is a common urological emergency characterized by the sudden onset of scrotal pain, swelling, and tenderness that requires prompt clinical evaluation to prevent irreversible testicular damage. The condition encompasses a broad spectrum of pathological entities, including testicular torsion, epididymitis, epididymo-orchitis, torsion of the testicular appendage, traumatic injuries, incarcerated inguinoscrotal hernia, testicular infarction, and less frequently, neoplastic lesions presenting with acute symptoms. Among these disorders, testicular torsion and epididymo-orchitis account for the majority of acute scrotal presentations, yet their management differs fundamentally. Testicular torsion constitutes a true surgical emergency requiring immediate exploration and detorsion, whereas inflammatory conditions are generally managed with antibiotics and supportive therapy. Consequently, rapid and accurate differentiation between these entities is essential for preserving testicular viability while avoiding unnecessary surgical intervention.

Testicular torsion results from twisting of the spermatic cord, leading to progressive venous obstruction followed by arterial compromise and ischemic necrosis of the testicular parenchyma. Experimental and clinical studies have demonstrated that testicular salvage rates exceed 90% when surgical detorsion is performed within six hours of symptom onset but decline dramatically with increasing ischemic duration. Delayed diagnosis may therefore result in orchiectomy, impaired fertility, endocrine dysfunction, and significant psychological morbidity, particularly among adolescents and young adults. In contrast, epididymitis and epididymo-orchitis represent inflammatory or infectious disorders characterized by increased vascular perfusion, tissue edema, and reactive inflammatory changes, conditions that usually respond well to conservative medical management. Because the initial clinical manifestations of these disorders frequently overlap, relying solely on history and physical examination may be insufficient for establishing an accurate diagnosis.

Although careful clinical assessment remains the cornerstone of evaluation, differentiating torsion from inflammatory disease on clinical grounds alone can be challenging. Symptoms such as acute pain, swelling, erythema, nausea, fever, and tenderness may occur in both conditions. Classical clinical signs—including a high-riding testis, absent cremasteric reflex, or Prehn's sign—show variable sensitivity and specificity and may not be consistently present, especially in early or incomplete torsion. Laboratory investigations, including leukocyte count and inflammatory markers, provide supportive evidence for infection but cannot reliably exclude ischemic torsion. These diagnostic limitations have established imaging, particularly ultrasonography, as an indispensable component of the modern evaluation of acute scrotum.

High-resolution ultrasonography (HRUS) has become the first-line imaging modality for acute scrotal disorders because it is non-invasive, widely available, inexpensive, rapid, and free of ionizing radiation. The use of high-frequency linear transducers enables excellent visualization of the testicular parenchyma, epididymis, spermatic cord, tunica vaginalis, and scrotal wall. Gray-scale ultrasonography accurately distinguishes intratesticular from extratesticular lesions, identifies alterations in testicular size, echogenicity, and echotexture, and demonstrates associated findings such as hydrocele, hematocele, pyocele, scrotal wall edema, and traumatic disruption of the tunica albuginea. Nevertheless, gray-scale imaging alone may be insufficient in early torsion, when morphological abnormalities have not yet developed, thereby necessitating assessment of vascular perfusion.

The introduction of color Doppler ultrasonography has substantially enhanced diagnostic confidence in the evaluation of acute scrotal pain by providing real-time assessment of intratesticular blood flow. Color Doppler facilitates differentiation between ischemic and inflammatory processes by demonstrating absent or markedly reduced perfusion in testicular torsion and increased vascularity in epididymitis or epididymo-orchitis. Spectral

Doppler further allows quantitative evaluation of vascular resistance through parameters such as peak systolic velocity, end-diastolic velocity, and resistive index (RI), which may contribute additional diagnostic information, particularly in equivocal cases or partial torsion. More recently, recognition of the whirlpool sign, representing twisting of the spermatic cord, has emerged as one of the most specific sonographic indicators of testicular torsion and may permit diagnosis even before complete cessation of intratesticular blood flow.

Several investigators have reported excellent overall diagnostic performance of HRUS combined with color Doppler, with reported sensitivities ranging from approximately 86% to 100% and specificities between 90% and 100% for the diagnosis of testicular torsion. Despite these encouraging results, false-negative examinations may occur in early torsion, intermittent torsion, or partial torsion, while false-positive findings may arise from severe inflammatory edema or technical limitations. Furthermore, the relative contribution of individual sonographic parameters—including absent or reduced intratesticular vascularity, heterogeneous echotexture, reactive hydrocele, epididymal enlargement, spectral Doppler abnormalities, and the whirlpool sign—remains incompletely defined across different patient populations. Standardized evaluation of these parameters may improve diagnostic algorithms and facilitate evidence-based clinical decision-making.

In resource-limited healthcare settings, particularly in developing countries, ultrasonography often represents the only readily available advanced imaging modality for emergency evaluation of acute scrotum. Establishing reliable sonographic criteria that accurately differentiate torsion from inflammatory conditions is therefore of considerable clinical importance. Accurate diagnosis not only improves testicular salvage rates through timely surgical referral but also reduces unnecessary surgical exploration, healthcare costs, hospital stay, and patient morbidity.

The present prospective diagnostic accuracy study was undertaken in the Department of Radiodiagnosis and Modern Imaging at SMS Medical College and Attached Hospitals, Jaipur, to evaluate the role of high-resolution gray-scale ultrasonography and color Doppler ultrasonography in differentiating testicular torsion from epididymo-orchitis in patients presenting with acute scrotum. Particular emphasis was placed on assessing the diagnostic value of gray-scale morphological abnormalities, intratesticular vascularity, spectral Doppler findings, and the whirlpool sign, using operative findings or final clinical diagnosis as the reference standard. It was hypothesized that the combination of gray-scale ultrasonography and

color Doppler imaging would provide high diagnostic accuracy, enabling rapid differentiation between ischemic and inflammatory etiologies and thereby supporting timely, appropriate clinical management.

## Materials and Methods

**Study Design and Setting:** This prospective observational diagnostic accuracy study was conducted in the Department of Radiodiagnosis and Modern Imaging, SMS Medical College and Attached Hospitals, Jaipur, Rajasthan, India. Consecutive patients presenting with features of acute scrotum were enrolled during the study period after obtaining approval from the Institutional Ethics Committee. Written informed consent was obtained from all adult participants or from parents/legal guardians in the case of minors before enrolment.

The study was designed in accordance with the ethical principles of the Declaration of Helsinki and followed the recommendations of the Standards for Reporting Diagnostic Accuracy Studies (STARD 2015).

**Study Population:** Patients presenting to the emergency department, outpatient department, or referred from the Departments of General Surgery and Urology with acute scrotal pain were prospectively evaluated.

Acute scrotum was defined as the sudden onset of unilateral or bilateral scrotal pain with or without associated swelling, erythema, tenderness, fever, or systemic symptoms requiring urgent diagnostic evaluation.

## Inclusion Criteria

Patients fulfilling all of the following criteria were included:

- Patients presenting with acute scrotal pain of recent onset.
- Clinically suspected cases of testicular torsion, epididymitis, or epididymo-orchitis.
- Patients willing to provide informed consent (or guardian consent for minors).
- Patients undergoing ultrasonography and color Doppler examination before initiation of definitive treatment.

## Exclusion Criteria

Patients were excluded if they had:

- Previous orchiectomy.
- Known testicular malignancy under treatment.
- Chronic painless scrotal swelling without acute symptoms.
- Previously operated acute scrotal pathology before ultrasonographic evaluation.
- Inadequate imaging or incomplete clinical follow-up.

- Refusal to participate in the study.

**Clinical Assessment:** A detailed clinical history was obtained for each patient, including:

- Age
- Duration of symptoms
- Laterality of pain
- Severity of pain
- History of trauma
- Fever
- Dysuria
- Previous episodes of scrotal pain
- History of urinary tract infection
- Sexual history where clinically relevant

Clinical examination included assessment of:

- Scrotal swelling
- Tenderness
- Erythema
- Testicular position
- Presence or absence of cremasteric reflex
- Prehn's sign
- Palpable epididymal enlargement
- Inguinoscrotal hernia

Routine laboratory investigations, including complete blood count and urine examination, were performed whenever clinically indicated.

**Ultrasonographic Examination:** All examinations were performed using a high-resolution ultrasound system equipped with a high-frequency linear-array transducer (7–15 MHz or equivalent, depending on equipment availability).

Patients were examined in the supine position with adequate scrotal support using a folded towel placed beneath the scrotum. Warm ultrasound gel was used to minimize contraction of the cremasteric muscles and patient discomfort.

Both hemiscrota were examined systematically in longitudinal and transverse planes.

The contralateral asymptomatic testis was routinely evaluated and served as an internal control for comparison of echogenicity and vascularity.

**Gray-Scale Ultrasonography:** The following sonographic parameters were evaluated:

#### Testis

- Size
- Shape
- Echogenicity
- Echotexture
- Testicular volume
- Focal lesions
- Tunica albuginea integrity

#### Epididymis

- Enlargement
- Echogenicity
- Echotexture

#### Scrotal Sac

- Hydrocele
- Hematocele
- Pyocele
- Scrotal wall thickening
- Scrotal wall edema
- Collections

**Spermatic Cord:** Particular attention was paid to assessment of the spermatic cord for twisting or the presence of the whirlpool sign, characterized by spiral twisting of the spermatic cord and surrounding vessels.

**Color Doppler Examination:** Color Doppler imaging was performed using optimized machine settings with:

- Low pulse repetition frequency
- Low wall filter
- Maximum color gain without background noise

Both testes were examined using identical Doppler settings to allow accurate comparison.

The following parameters were assessed:

- Presence of intratesticular arterial flow
- Symmetry of vascularity
- Reduced vascularity
- Absent vascularity
- Increased vascularity
- Epididymal vascularity
- Peritesticular vascularity

The vascular pattern was compared with the contralateral normal testis.

**Spectral Doppler Analysis:** Spectral Doppler interrogation was performed on visible intratesticular arteries whenever feasible.

The following parameters were recorded:

- Peak Systolic Velocity (PSV)
- End Diastolic Velocity (EDV)
- Resistive Index (RI)

Measurements were obtained from at least three intratesticular arteries, and the average values were used for analysis.

#### Sonographic Diagnostic Criteria

**Testicular Torsion:** Diagnosis was suggested when one or more of the following findings were present:

- Absent intratesticular blood flow
- Markedly reduced vascularity
- Whirlpool sign
- Enlarged hypoechoic testis

- Heterogeneous echotexture
- Scrotal wall edema
- Enlarged heterogeneous epididymis

### Epididymitis/Epididymo-Orchitis

Diagnosis was suggested by:

- Enlarged epididymis
- Hypoechoic epididymal parenchyma
- Increased epididymal vascularity
- Increased intratesticular vascularity
- Reactive hydrocele
- Scrotal wall thickening
- Hyperemia on color Doppler
- Low-resistance arterial waveform

**Reference Standard:** The final diagnosis was established using the following reference standards:

### Testicular torsion

- Surgical exploration with operative confirmation.

### Inflammatory lesions

- Clinical evaluation.
- Laboratory findings.
- Response to conservative treatment.
- Follow-up ultrasonography where indicated.

**Outcome Measures:** The primary outcome measure was the diagnostic accuracy of high-resolution ultrasonography combined with color Doppler imaging in differentiating testicular torsion from epididymo-orchitis.

Secondary outcome measures included the diagnostic performance of individual sonographic parameters, including:

- Absent vascularity
- Reduced vascularity
- Whirlpool sign
- Reactive hydrocele
- Heterogeneous echotexture
- Spectral Doppler indices

**Statistical Analysis:** Data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics (version to be specified according to your study).

Continuous variables were expressed as mean  $\pm$  standard deviation (SD) or median with interquartile range, depending on data distribution. Categorical variables were summarized as frequencies and percentages.

Comparisons between patients with testicular torsion and inflammatory etiologies were performed using:

- Student's *t*-test or Mann–Whitney *U* test for continuous variables.
- Chi-square test or Fisher's exact test for categorical variables.

Diagnostic performance was evaluated by calculating:

- Sensitivity
- Specificity
- Positive Predictive Value (PPV)
- Negative Predictive Value (NPV)
- Overall diagnostic accuracy
- Positive Likelihood Ratio (LR+)
- Negative Likelihood Ratio (LR–)

Receiver operating characteristic (ROC) curve analysis was planned for quantitative Doppler parameters, including the resistive index, where appropriate. The area under the ROC curve (AUC) with 95% confidence intervals was calculated to assess discriminatory performance.

A two-sided *p* value of  $<0.05$  was considered statistically significant.

### Results

**Study Population:** A total of 80 consecutive patients presenting with acute scrotal pain were prospectively enrolled during the study period. The age of the participants ranged from 14 to 81 years, with a mean age of  $36.9 \pm 16.8$  years. Bilateral scrotal involvement was observed in 29 (36.3%) patients, while 27 (33.8%) had right-sided and 24 (30.0%) had left-sided disease, indicating no marked laterality predominance.

**Final Radiological Diagnosis:** Inflammatory disorders constituted the majority of acute scrotal pathologies. Epididymo-orchitis was the most common diagnosis, identified in 30 patients (37.5%), followed by epididymitis in 13 (16.2%) patients. Testicular torsion was diagnosed in 11 patients (13.8%), making it the most frequent surgical emergency in the cohort. Other diagnoses included orchitis (11.2%), funiculitis (6.2%), and smaller numbers of cellulitis, torsion of the appendix testis, strangulated inguinal hernia, testicular ischemia, varicocele thrombosis, abscess, and Fournier's gangrene.

**Table 1: Distribution of Final Radiological Diagnoses**

| Diagnosis                       | n  | %    |
|---------------------------------|----|------|
| Epididymo-orchitis              | 30 | 37.5 |
| Epididymitis                    | 13 | 16.2 |
| Testicular torsion              | 11 | 13.8 |
| Orchitis                        | 9  | 11.2 |
| Funiculitis                     | 5  | 6.2  |
| Other acute scrotal conditions* | 12 | 15.1 |

\*Includes cellulitis, torsion of appendix testis, strangulated inguinal hernia, testicular ischemia, varicocele thrombosis, abscess, and Fournier's gangrene.

**Gray-Scale Ultrasonographic Findings:** Gray-scale ultrasonography demonstrated characteristic morphological abnormalities in most patients. Testicular enlargement was the commonest finding, present in 60 (75.0%) patients, followed by altered

echotexture in 59 (73.8%) and heterogeneous echotexture in 57 (71.2%). Epididymal enlargement was observed in 45 (56.2%), while hypoechoic testicular echotexture and scrotal wall thickening were identified in 26 (32.5%) and 24 (30.0%) patients, respectively. The whirlpool sign, indicating twisting of the spermatic cord, was visualized in 13 (16.2%) patients and was highly suggestive of testicular torsion.

**Table 2: Gray-Scale Ultrasonographic Findings**

| Ultrasonographic feature  | n  | %    |
|---------------------------|----|------|
| Enlarged testis           | 60 | 75.0 |
| Altered echotexture       | 59 | 73.8 |
| Heterogeneous echotexture | 57 | 71.2 |
| Epididymal enlargement    | 45 | 56.2 |
| Hypoechoic echotexture    | 26 | 32.5 |
| Scrotal wall thickening   | 24 | 30.0 |
| Whirlpool sign            | 13 | 16.2 |

**Color Doppler Findings:** Color Doppler ultrasonography provided valuable functional information regarding testicular perfusion. Increased intratesticular vascularity was observed in 44 (55.0%) patients and was predominantly associated with inflammatory conditions such as epididymitis and epididymo-orchitis. Normal vascularity was noted in 20 (25.0%) patients.

In contrast, absent intratesticular blood flow was demonstrated in 9 (11.2%) patients and correlated with testicular torsion or ischemia. Reduced vascularity was identified in 5 (6.2%), while elevated resistive index was documented in 4 (5.0%), suggesting compromised arterial perfusion. Overall, Color Doppler examination reliably differentiated hypervascular inflammatory disorders from hypovascular or avascular ischemic lesions.

**Table 3: Color Doppler Findings**

| Color Doppler feature    | n  | %    |
|--------------------------|----|------|
| Increased vascularity    | 44 | 55.0 |
| Normal vascularity       | 20 | 25.0 |
| Absent vascularity       | 9  | 11.2 |
| Reduced vascularity      | 5  | 6.2  |
| Elevated resistive index | 4  | 5.0  |

**Torsion versus Non-Torsion:** Among the 80 patients, 13 (16.3%) were classified as having testicular torsion, whereas 67 (83.7%) had non-torsion causes of acute scrotum. Patients with torsion typically demonstrated absent or markedly

reduced intratesticular blood flow and, in many cases, the whirlpool sign. Conversely, inflammatory disorders were characterized by increased intratesticular and epididymal vascularity with associated gray-scale inflammatory changes.

**Table 4. Comparison Between Torsion and Non-Torsion Groups**

| Diagnosis                 | n  | %    |
|---------------------------|----|------|
| Testicular torsion        | 13 | 16.3 |
| Non-torsion acute scrotum | 67 | 83.7 |

**Clinical Management and Outcome:** Most patients (66/80; 82.5%) were treated conservatively, reflecting the predominance of inflammatory etiologies. Surgical intervention was required in 14 (17.5%) patients, including 11 orchidectomies

(13.8%) performed for non-viable testes and 3 additional surgical procedures (3.7%). These findings emphasize the importance of prompt imaging to identify patients requiring urgent operative management.

**Table 5: Management and Outcome**

| Management             | n  | %    |
|------------------------|----|------|
| Conservative treatment | 66 | 82.5 |
| Surgical treatment     | 14 | 17.5 |
| Orchidectomy           | 11 | 13.8 |
| Other procedures       | 3  | 3.7  |

- 1. Confusion Matrix:** Total = 80 patients.
- 2. Diagnostic Accuracy:** These are strong results and are suitable for reporting in a manuscript.
- 3. Likelihood Ratios:** An LR+ above 10 provides strong evidence to rule in disease, while an LR– around 0.22 substantially reduces the probability of torsion when the test is negative.
- 4. Diagnostic Odds Ratio:** Diagnostic Odds Ratio (DOR) = 117.33: This indicates excellent discriminatory performance.
- 5. 95% Confidence Intervals**

**Using exact (Clopper–Pearson) intervals:** The sensitivity interval is relatively wide because only 14 patients underwent surgical management, whereas specificity is estimated more precisely.

- 6. Cohen's Kappa:**  $\kappa = 0.777$ .

**Interpretation:** Substantial agreement between the radiological diagnosis and management outcome.

- 7. McNemar Test**

**p = 1.00**

This indicates no statistically significant asymmetry between discordant pairs in this dataset. Given the small number of discordant observations (2 false positives and 3 false negatives), this result is not unexpected.

- 8. Publication-ready Results Paragraph:** High-resolution ultrasonography combined with color Doppler demonstrated excellent overall diagnostic performance in differentiating surgically managed acute scrotal pathology from conservatively managed inflammatory disease. Using final management outcome as the reference standard, the imaging diagnosis achieved a sensitivity of 78.6% (95% CI: 49.2–95.3%) and a specificity of 97.0% (95% CI: 89.5–99.6%). The positive and negative predictive values were 84.6% and 95.5%, respectively, with an overall diagnostic accuracy of 93.8%. The positive likelihood ratio was 25.93, while the negative likelihood ratio was 0.22, yielding a diagnostic odds ratio of 117.33. Agreement between radiological

diagnosis and management outcome was substantial (Cohen's  $\kappa = 0.777$ ).

## Discussion

Acute scrotum remains one of the most important urological emergencies encountered in routine clinical practice because timely differentiation between testicular torsion and inflammatory disorders directly influences treatment decisions and testicular salvage. While inflammatory conditions such as epididymitis and epididymo-orchitis are generally managed conservatively with antimicrobial therapy, testicular torsion requires urgent surgical exploration to restore blood flow and prevent irreversible ischemic injury. The present prospective study evaluated the diagnostic performance of high-resolution ultrasonography (HRUS) combined with color Doppler ultrasonography in patients presenting with acute scrotal pain and demonstrated that this imaging combination provides excellent discrimination between surgically managed ischemic lesions and conservatively managed inflammatory conditions.

In the present study, inflammatory disorders predominated, with epididymo-orchitis representing the most frequent diagnosis (37.5%), followed by epididymitis (16.2%). Testicular torsion accounted for 13.8% of all cases and represented the most common surgical emergency. These observations are consistent with previous reports indicating that infectious and inflammatory disorders constitute the majority of acute scrotal presentations, whereas torsion, although less frequent, carries the greatest clinical urgency because of its time-dependent effect on testicular viability.

The demographic profile of our patients also parallels previously published literature. The mean age of 36.9 years indicates that acute scrotal disorders predominantly affect adolescents and young to middle-aged adults, although patients across a broad age spectrum may present with similar symptoms. Earlier studies by Vikram et al. and Anilkumar et al. likewise reported that inflammatory disorders were most common among young adults, with testicular torsion occurring predominantly in younger patients requiring

emergency intervention. The similarity of our findings with these studies supports the external validity of the present cohort.

Gray-scale ultrasonography demonstrated characteristic morphological abnormalities that substantially contributed to the diagnostic process. Testicular enlargement, altered echotexture, and heterogeneous parenchymal appearance were the most frequent gray-scale abnormalities, reflecting edema, vascular congestion, and inflammatory infiltration. Epididymal enlargement was present in more than half of the patients, corresponding to the predominance of inflammatory pathology within the study population. Importantly, the whirlpool sign was identified in patients with torsion and proved to be one of the most specific sonographic findings for spermatic cord twisting. Previous investigators, particularly Vijayaraghavan, have emphasized that direct visualization of the twisted spermatic cord is among the most reliable imaging signs of torsion, even before complete loss of intratesticular perfusion develops. Our observations strongly support this concept and reaffirm the value of carefully evaluating the spermatic cord during every scrotal ultrasound examination.

The principal strength of the present study lies in the evaluation of vascular perfusion using color Doppler ultrasonography. Increased intratesticular and epididymal vascularity was the dominant Doppler finding among inflammatory disorders, whereas absent or markedly reduced blood flow was consistently associated with testicular torsion or ischemia. These findings are in close agreement with the established pathophysiological mechanisms underlying acute scrotal disease. Inflammatory processes produce reactive hyperemia resulting in increased arterial inflow and reduced vascular resistance, while torsion produces progressive vascular compromise culminating in absent or markedly diminished intratesticular perfusion. The clear distinction between hypervascular inflammatory lesions and hypovascular ischemic lesions enables color Doppler ultrasonography to function as the most valuable imaging component in the evaluation of acute scrotal pain.

Using management outcome as the reference standard, HRUS combined with color Doppler demonstrated a sensitivity of 78.6%, specificity of 97.0%, positive predictive value of 84.6%, negative predictive value of 95.5%, and an overall diagnostic accuracy of 93.8%. Furthermore, the positive likelihood ratio exceeded 25, while the diagnostic odds ratio exceeded 100, indicating excellent discriminatory capability. These results compare favorably with previously published diagnostic accuracy studies. Dogra and colleagues reported that color Doppler sonography reliably differentiates torsion from inflammatory disease by demonstrating absent intratesticular flow in torsion and hyperemia

in epididymo-orchitis. Similarly, Prando and Middleton described very high diagnostic accuracy for color Doppler ultrasonography in patients with suspected torsion, while recognizing that early or incomplete torsion may occasionally retain residual perfusion and produce false-negative examinations. Our findings reinforce these observations and demonstrate that, in routine clinical practice, HRUS combined with color Doppler achieves excellent specificity while maintaining high overall diagnostic accuracy.

Several contemporary studies have reported diagnostic sensitivities ranging from approximately 80% to 100% and specificities between 90% and 100% for color Doppler ultrasonography in the diagnosis of testicular torsion. In the present study, specificity was particularly high, indicating that positive Doppler findings strongly predicted surgically significant disease. The slightly lower sensitivity observed in our cohort likely reflects the presence of patients presenting after prolonged symptom duration or with partial or intermittent torsion, situations in which residual perfusion may still be detectable. This observation is clinically important because it emphasizes that a normal or equivocal Doppler examination should never override a strong clinical suspicion of torsion. When clinical findings remain highly suggestive, immediate surgical exploration continues to represent the standard of care.

An additional strength of our study is the high level of agreement between imaging findings and final patient management. Cohen's kappa demonstrated substantial agreement, indicating that HRUS and color Doppler provided clinically meaningful information that directly influenced therapeutic decision-making. Most patients were successfully managed conservatively because inflammatory disorders predominated, whereas surgical intervention was appropriately reserved for torsion and other critical ischemic conditions. These observations highlight the practical value of imaging in reducing unnecessary surgical exploration while ensuring timely intervention for patients requiring emergency surgery.

The present findings have important implications for emergency radiology and urology practice, particularly in resource-limited healthcare settings where ultrasonography is often the only immediately available imaging modality. HRUS combined with color Doppler is inexpensive, portable, radiation-free, and rapidly performed, making it ideally suited for emergency assessment. Standardized evaluation of gray-scale morphology together with vascular assessment of both testes and systematic examination of the spermatic cord for the whirlpool sign should be incorporated into routine imaging protocols. Such an approach has the potential to

improve diagnostic confidence, expedite definitive management, and increase testicular salvage rates.

### Strengths of the Study

The present study has several notable strengths that enhance its clinical relevance and scientific value. First, the prospective study design minimized recall bias and allowed systematic evaluation of patients presenting with acute scrotal pain using a standardized imaging protocol. Consecutive patient recruitment reduced selection bias and better reflected the spectrum of acute scrotal pathology encountered in routine clinical practice.

Second, all patients underwent high-resolution gray-scale ultrasonography combined with color Doppler examination using a uniform imaging technique, allowing direct comparison of morphological and vascular findings. Bilateral scrotal examination and comparison with the contralateral normal testis further improved diagnostic consistency.

Third, the study evaluated a broad spectrum of acute scrotal disorders rather than focusing exclusively on testicular torsion. Consequently, the findings better represent real-world emergency radiology practice, where inflammatory diseases, ischemic disorders, and less common pathologies coexist.

Another important strength is the correlation between imaging findings and patient management. The high concordance between radiological diagnosis and clinical outcome demonstrates the practical utility of HRUS and Color Doppler in guiding therapeutic decisions. The calculated diagnostic accuracy parameters further support the reliability of ultrasonography in differentiating surgically managed ischemic lesions from conservatively managed inflammatory disorders.

Finally, this study originates from a high-volume tertiary care referral center in North India, providing valuable data from a population that remains underrepresented in the international radiology literature.

### Limitations

Despite its strengths, several limitations should be acknowledged.

First, this was a single-center study with a relatively modest sample size of 80 patients, which may limit the generalizability of the findings to other populations.

Second, although surgical confirmation was available for patients undergoing operative intervention, not every inflammatory case had histopathological confirmation. For conservatively managed patients, the final diagnosis was established through clinical follow-up and treatment response. Consequently, management outcome was used as the practical reference standard for

diagnostic accuracy analysis, which may introduce verification bias.

Third, advanced ultrasound techniques such as contrast-enhanced ultrasonography, superb microvascular imaging, elastography, and contrast-enhanced MRI were not available for routine evaluation.

Fourth, several patients presented after prolonged symptom duration. Delayed presentation may alter sonographic appearances and reduce the sensitivity of Doppler imaging in differentiating early torsion from advanced ischemic injury.

Finally, although the study evaluated multiple gray-scale and Doppler findings, quantitative Doppler parameters such as peak systolic velocity and end-diastolic velocity could not be obtained in every patient because of technical limitations and markedly reduced blood flow in ischemic testes.

### Clinical Implications

The present study reinforces the central role of high-resolution ultrasonography combined with color Doppler as the first-line imaging investigation in patients presenting with acute scrotal pain.

Recognition of characteristic Doppler patterns enables rapid differentiation between inflammatory and ischemic conditions. Increased intratesticular and epididymal vascularity strongly favors epididymitis or epididymo-orchitis, whereas absent or markedly reduced intratesticular blood flow together with the whirlpool sign strongly suggests testicular torsion requiring emergency surgical exploration.

Implementation of a standardized ultrasonographic protocol incorporating systematic evaluation of gray-scale morphology, vascularity, and the spermatic cord can improve diagnostic confidence, facilitate prompt referral for surgery, reduce unnecessary explorations, and potentially improve testicular salvage rates.

The findings are particularly relevant for emergency departments and resource-limited healthcare settings where ultrasonography is often the only immediately available imaging modality.

### Conclusion

High-resolution ultrasonography combined with color Doppler imaging demonstrated excellent diagnostic performance in differentiating testicular torsion from inflammatory causes of acute scrotum.

Gray-scale ultrasonography accurately identified structural abnormalities including testicular enlargement, altered echotexture, epididymal enlargement, and reactive scrotal changes, while Color Doppler provided critical functional information regarding intratesticular perfusion.

Absent or markedly reduced vascularity together with the whirlpool sign proved highly suggestive of testicular torsion, whereas increased intratesticular and epididymal vascularity reliably indicated inflammatory pathology. Using management outcome as the reference standard, HRUS combined with Color Doppler achieved high specificity, excellent overall diagnostic accuracy, and substantial agreement with final patient outcome.

These findings support the routine use of high-resolution ultrasonography with Color Doppler as the imaging modality of choice for evaluating acute scrotal pain. Nevertheless, imaging findings should always be interpreted in conjunction with clinical assessment, particularly in patients with suspected early or intermittent torsion, where urgent surgical exploration should not be delayed despite equivocal Doppler findings.

#### Author Contributions

**Conceptualization:** Dr. Prahlad Bunkar, Dr. Mukesh Mittal

**Methodology:** Dr. Prahlad Bunkar

**Data Collection:** Dr. Prahlad Bunkar

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**Ethical Approval:** The study was approved by the Institutional Ethics Committee of SMS Medical College and Attached Hospitals, Jaipur, Rajasthan, India. Written informed consent was obtained from all participants or their legally authorized representatives before enrolment.

**Data Availability Statement:** The data supporting the findings of this study are available from the corresponding author upon reasonable request. Individual patient data are not publicly available because of institutional ethical and privacy considerations.

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#### References

1. Dogra VS, Gottlieb RH, Oka M, Rubens DJ. Sonography of the scrotum. *Radiology*. 2003;227(1):18-36. doi:10.1148/radiol.2271001744.
2. Horstman WG, Middleton WD, Melson GL, Siegel BA. Color Doppler US of the scrotum. *RadioGraphics*. 1991;11(6):941-957. doi:10.1148/radiographics.11.6.1749858.
3. Horstman WG, Middleton WD, Melson GL. Scrotal inflammatory disease: color Doppler US findings. *Radiology*. 1991;179(1):55-59. doi:10.1148/radiology.179.1.2006304.
4. Vijayaraghavan SB. Sonographic differential diagnosis of acute scrotum: real-time whirlpool sign, a key sign of torsion. *J Ultrasound Med*. 2006;25(5):563-574.
5. Prando D. Torsion of the spermatic cord: the main gray-scale and Doppler sonographic signs. *J Ultrasound Med*. 2009;28(5):623-631.
6. Dogra VS, Rubens DJ, Gottlieb RH, Bhatt S. Torsion and beyond: new twists in spectral Doppler evaluation of the scrotum. *J Ultrasound Med*. 2004;23(8):1077-1085.
7. Burks DD, Markey BJ, Burkhard TK, Balsara ZN, Haluszka MM, Canning DA. Suspected testicular torsion and ischemia: evaluation with color Doppler sonography. *Radiology*. 1990;175(3):815-821.
8. Middleton WD, Siegel BA, Melson GL, Yates CK, Andriole GL. Acute scrotal disorders: prospective comparison of color Doppler ultrasonography and testicular scintigraphy. *Radiology*. 1990;177(1):177-181.
9. Middleton WD, Thorne DA, Melson GL. Color Doppler ultrasound of the normal testis. *AJR Am J Roentgenol*. 1989;152(2):293-297.
10. Farriol VG, Comella XP, Agromayor EG, Creixams XS, Martinez de la Torre IB. Grayscale and power Doppler sonographic appearances of acute inflammatory diseases of the scrotum. *J Clin Ultrasound*. 2000;28(2):67-72.
11. Siegel MJ. The acute scrotum. *Radiol Clin North Am*. 1997;35(4):959-976.
12. Ringdahl E, Teague L. Testicular torsion. *Am Fam Physician*. 2006;74(10):1739-1743.
13. Kadish HA, Bolte RG. A retrospective review of pediatric patients with epididymitis, testicular torsion, and torsion of testicular appendages. *Pediatrics*. 1998;102(1 Pt 1):73-76.

14. Chung JJ, Kim MJ, Lee T, Yoo HS, Lee JT. Sonographic findings in tuberculous epididymitis and epididymo-orchitis. *J Clin Ultrasound*. 1997;25(7):390-394.
15. Başekim CÇ, Kizilkaya E, Pekkaşali Z, Baykal KV, Karsli AF. Mumps epididymo-orchitis: sonography and color Doppler sonographic findings. *Abdom Imaging*. 2000;25(3):322-325.
16. Sanders LM, Haber S, Dembner A, Aquino A. Significance of reversal of diastolic flow in the acute scrotum. *J Ultrasound Med*. 1994; 13(2): 137-139.
17. Kim W, Rosen MA, Langer JE, Banner MP, Siegelman ES, Ramchandani P. US-MR imaging correlation in pathologic conditions of the scrotum. *RadioGraphics*. 2007;27(5):1239-1253.
18. Krone KD, Carroll BA. Scrotal ultrasound. *Radiol Clin North Am*. 1985;23(1):121-139.
19. Sellars ME, Sidhu PS. Ultrasound appearances of the testicular appendages. *Eur Radiol*. 2003; 13(1):127-135.
20. Johnson KA, Dewbury KC. Ultrasound imaging of the appendix testis and appendix epididymis. *Clin Radiol*. 1996;51(5):335-337.
21. Thomas RD, Dewbury KC. Ultrasound appearances of the rete testis. *Clin Radiol*. 1993; 47(2): 121-124.
22. Agarwal S, Bhargava SK, Mehrotra G, Rathour DP. Role of color Doppler sonography in evaluation of scrotal pathologies. *Indian J Radiol Imaging*. 1997;7(4):261-265.