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A simplified ultrasound approach to diagnose testicular torsion and predict unsalvageable testis

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Abstract

Aims: To develop a decision tree model using US features to differentiate testicular torsion and other conditions of acute scrotum and to investigate predictive parameters of unsalvageable testis in testicular torsion. **Materials and methods**: Scrotal US was reviewed in patients aged <30 years who presented with acute scrotum from 2014 to 2020. US findings of whirlpool sign, testicular volume ratio, heterogeneous echotexture, testicular vascularity, epididymis enlargement and/or hyperemia, and avascular nodule were evaluated and compared. A decision tree model was created using the conditional inference tree analysis and the accuracy was calculated. Univariate logistic regression analysis was performed to find out the predictive US features of unsalvageable testes. **Results**: Total of 381 patients (13.2±7.2 years old; range, 1 day-30 years) were included. Thirty-four patients were diagnosed with testicular torsion, and the others with orchitis or epididymo-orchitis (n=59), epididymitis (n=264), and appendage torsion (n=24). In the conditional inference tree analysis, whirlpool sign, avascular nodule, and increased testicular vascularity were the most significant discriminators (p<0.001), and the whirlpool sign was the first discriminator. The overall accuracy of the conditional inference tree was 91.1% (95% confidence interval [CI], 87.8-93.7%). Heterogeneous echotexture (odds ratio [OR], 74.99; 95% CI, 2.75-2046.26; p=0.01) and symptom-to-operation time >24 h (OR, 49.28; 95% CI, 1.92-1262.03; p=0.02) were significant predictors of unsalvageable testis. **Conclusions**: Conditional inference tree analysis showed that the whirlpool sign of the spermatic cord, avascular nodule, and altered testicular vascularity were significant discriminators. Heterogeneous echotexture and symptom-to-operation delay were important prognostic factors for unsalvageable testis.

Keywords: spermatic cord torsion; ultrasonography; pediatric

Introduction

Testicular torsion is defined as twisting of the spermatic cord and testis, resulting in interruption of the vascular supply to the testis [1,2]. Reduced blood flow causes severe pain, and patients may also present with nausea, vomiting, and swollen erythematous scrotum [3]. Its incidence is 1 per 4000 men younger than 25 years [1,3,4]. Testicular torsion is a surgical emergency in which diagnosis and treatment should not be delayed because it can cause testicular ischemia, resulting in necrosis, infertility, and cosmetic deformity [1]. Considering that infants and adolescent boys are most often affected, prompt diagnosis is important [4-6].

Differential diagnosis is important because of the occurrence of numerous common diseases, such as appendage torsion and epididymo-orchitis, which can evoke similar symptoms and mimic testicular torsion. Testicular torsion accounts for 26-27% of children with acute scrotum [7]. Among imaging tools, ultrasound (US) is a mainstay and helpful technique in differentiating the causes of acute scrotal pain. Multiple US findings (absent or decreased blood flow in the testis, presence of spiral, whirlpool, or knot twist, increased or heterogeneous testicular echogenicity, and inverted testicular orientation) are helpful for the diagnosis of testicular torsion [8].

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Testicular torsion is an acute condition in which a patient can present to a hospital at any time of the day, and scrotal US is usually performed by different experience levels of operators in clinical practice. Moreover, as the use of point-of-care ultrasound (POCUS) has increased, more urologists or emergency physicians are expected to perform US to detect testicular torsion in patients with acute scrotum [9]. Conditional inference tree analysis estimates the regression relationship in an intuitive way and is easy to interpret [10]. In acute scrotum setting, accurate diagnosis can prove difficult due to overlapping ultrasonographic features (e.g., epididymal swelling) or atypical cases (e.g., testis torsion with preserved vascular flow). A simplified decision tree model would be helpful for different levels of operators in diagnosing testicular torsion more accurately by providing an intuitive step-by-step approach; however, no studies so far have investigated. Therefore, the first aim of our study was to develop a simplified and easy, conditional tree model to differentiate testicular torsion and other various conditions of acute scrotum. Of note, prediction of testicular viability is an important factor in clinical decision making. Specifically, patients with viable testis need urgent surgery to avoid testicular necrosis. For cases in which non-viable testis is predicted, clinicians can explain the possibility of orchiectomy or testicular atrophy after orchiopexy to patients in advance. Therefore, the second aim of this study was to determine the predictive factors of testicular viability in patients with testicular torsion.

Materials and methods

Patients

Our Institutional Review Board approved this study and waived the requirement for informed consent (HDT 2021-03-016). We retrospectively reviewed scrotal US performed in children and young adults (≤30 years old) for acute scrotum between January 2014 and June 2020. Among the 424 consecutive patients who underwent scrotal US, 43 patients were excluded because of the following reasons: non-evaluable volume due to poor US image quality (n=24); underlying undescended and small-sized testis (n=3); US performed only after manual reduction or orchiopexy (n=5); single testis due to prior orchiectomy for torsion (n=5); revealed inguinal hernia on US (n=2); and revealed soft tissue infections such as abscess and cellulitis (n=4). Finally, 381 patients were included in the analysis.

US examination

Scrotal US was performed using a Philips iU-22 (Philips Healthcare, Bothell, WA) with a 5-12 MHz linear transducer or Canon Aplio i800 (Canon Medical Systems, Tokyo, Japan) with an i18LX5 linear probe (4-18 MHz). Only Philips iU-22 was available in our institution until 2018. Philips iU-22 and Canon Aplio i800 were used since 2019. Over the 6 years, a total of six radiology trainees (with one to four years of experience in radiology) and one board-certified pediatric radiologist (with 7 years of experience in radiology) performed US. For the iU-22 system, color Doppler imaging was optimized to show low flow velocities using a low pulse repetition frequency, a low wall filter, and a 70-90% color gain. For the Canon Aplio i800 system, the predetermined flow setting of the machine was constantly selected by operators, which was optimized by dialing up the color gain to a level where color noise was just becoming perceptible in unmoving structures. The flow velocity was 6.1 cm/s, and a mid-level filter was used. During the exam, the transverse field-of-view was first obtained to compare each testis in both the grayscale and color Doppler images. Each testis was then evaluated in both the longitudinal and transverse planes.

US analysis

One resident (with 3 years of experience in radiology) and one board-certified pediatric radiologist (with 7 years of experience in radiology) independently reviewed scrotal US on a picture archiving and communication system (PACS). They had a training session with 20 cases before reading. Discrepancies in interpretation were resolved by consensus of the reviewers. All clinical information was blinded to reviewers, except for the laterality of the symptomatic side. The reviewers confirmed the following US characteristics in symptomatic testis: the whirlpool sign, altered lie, testicular volume ratio, heterogeneous echotexture, testicular vascularity (increased, normal, decreased, absent), epididymis enlargement and/or hyperemia, and avascular nodule at the superior pole of the testis [11]. The representative images of the above US characteristics are presented in the supplementary figures (supplementary fig 1-9). To calculate the volume ratio, the volume of the symptomatic side was divided by that of the contralateral side. The testicular volumes were routinely measured during the examination using the formula (length (L) × width (W) × height (H) × 0.52) and stored on PACS images. In patients with bilateral symptoms, the volume of the larger testis was divided by that of the contralateral side.

Clinical outcome

The diagnosis of testicular torsion was made based on surgical findings. In patients who did not undergo emergency surgery due to markedly relieved symptoms after manual reduction, the diagnosis of testicular torsion was made clinically by physical examination and sonographic findings. Non-salvageable testis was defined as orchiec-

tomy or orchiopexy with subsequent atrophy. Subsequent atrophy was defined as a >20% decreased volume compared with the contralateral testis on follow-up US [12]. The final diagnoses of acute scrotum other than testicular torsion (i.e., epididymitis, orchitis or epididymo-orchitis, appendage torsion) were collected through electronic medical records documented by urologists or emergency physicians. Clinical information including age, side of symptom, and interval between symptom onset and operation was retrieved from electronic medical records.

Statistical analysis

One-way analysis of variance and Student's t-test were used to compare the mean of continuous variables (age and volume ratio) among the groups. Pearson's chi-square and Fisher's exact tests were used to compare the proportion of categorical variables (laterality, symptom-to-operation time > 24 h, presence of various US findings) among the groups, as appropriate. Conditional inference tree analysis was conducted to construct a decision tree model to classify patients into testicular torsion and other etiologies of acute scrotum (epididymitis, orchitis or epididymo-orchitis, and appendage torsion). Conditional inference trees estimate a regression relationship using binary recursive partitioning in a conditional inference [13]. The accuracy of the decision tree model was then calculated. Univariate logistic regression analysis was conducted to assess the predictive US parameters of unsalvageable testes. The maximum likelihood estimates did not exist because of the small sample size. Data were analyzed using a logistic regression model with Firth's penalized maximum likelihood estimation. Kappa values between 0.61 and 0.80 and >0.80 indicate substantial and almost perfect agreement, respectively [14] Statistical analyses were performed with R software using the "partykit" package (version 3.5.2; R Foundation for Statistical Computing, Vienna, Austria) and SAS (version 9.4; SAS Institute Inc., Cary, NC, USA). A 2-sided p value of <0.05 was generally considered a minimum level of statistical significance.

External validation

To assess the efficiency of our decision tree model in different level of operators, one resident with one year of experience in radiology reviewed scrotal US exams conducted for acute scrotum between January 2021 and December 2021, according to the decision tree model. This cohort of external validation was separate from the cohort used for the modeling of decision tree analysis and comprised 106 patients (13.2±6.3years old; range, 4 months–30 years old). The accuracy of the decision tree model was calculated in the external validation cohort.

Results

Patient characteristics

A total of 381 patients were included (13.2±7.2 years old; range, 1 day-30 years old). Thirty-four patients were diagnosed with testicular torsion. Among the patients with testicular torsion, 26 underwent orchiopexy, 6 underwent orchiectomy, and 2 were discharged without emergency surgery because of markedly relieved symptoms after manual reduction. Other diagnoses included 59 orchitis or epididymo-orchitis (7 orchitis, 52 epididymo-orchitis), 264 epididymitis, and 24 appendage torsion. The patient characteristics of each disease group are presented in Table I. The mean age of the patients with appendage torsion was significantly younger than those with other etiologies of acute scrotum (p=0.049 in appendage torsion vs. testicular torsion, p=0.02 in appendage torsion vs. orchitis or epididymo-orchitis, P=0.04 in appendage torsion vs. epididymitis). The pathologic results of all six patients who underwent orchiectomy were revealed as testis infarction, and all showed heterogeneous echotexture on preoperative US. The average follow-up period of orchiopexy cases was 108.4 days (range, 26–557 days).

Sonographic characteristics of acute scrotal diseases

The US characteristics of the four disease groups are summarized in Table II. The whirlpool sign (91.2%,

Table I. Patient characteristics of each disease group of acute scrotum

	Testicular torsion	Orchitis or epididymo-orchitis	Epididymitis	Appendage torsion	p value
Patients (number)	34	59	264	24	
Age (year), mean±SD (range)	14.12±5.88 (1days~28)	14.29±7.54 (4 months~29)	13.25±7.50 (3 months~29)	9.17±2.90† (2~16)	0.02*
Laterality of symptomatic side					
Right	6 (17.6%)	27 (45.8%)	120 (45.5%)	9 (37.5%)	
Left	28 (82.4%)	30 (50.8%)	124 (47.0%)	15 (62.5%)	
Both	0 (0.0%)	2 (3.4%)	20 (7.6%)	0 (0.0%)	

*p values obtained from one-way analysis of variance followed by Tukey's test. †p<0.05, compared with torsion, orchitis or epididymo-orchitis, and epididymitis.

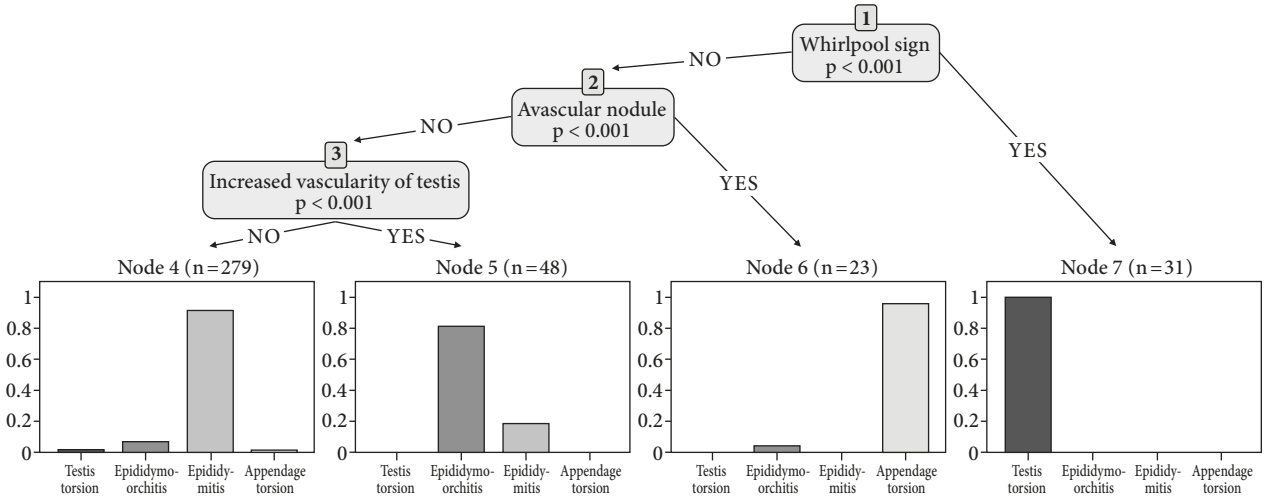

Fig 1. Conditional inference tree model using US features to differentiate testicular torsion and other various conditions of acute scrotum.

31/34) and altered lie (17.6%, 6/34) were only detected in testicular torsion. Heterogeneous echotexture was more common in testicular torsion (38.2%, 13/34) than in the other groups. Epididymal enlargement and/or hyperemia was common in the group with orchitis or epididymo-orchitis (61.0%, 36/59) and appendage torsion (50.0%, 12/24). Normal vascularity was rare (8.8%, 3/34) in the group with testicular torsion, and testicular torsion usually demonstrated avascularity (82.4%, 28/34). Increased vascularity of the testis was common in the group with orchitis or epididymo-orchitis (66.1%, 38/59). Avascular nodules were usually observed in the group with appendage torsion (91.7%, 22/24). The volume ratio between the symptomatic and contralateral sides of the testis was significantly higher in the testicular torsion group than in the other groups by post hoc test (all $p<0.001$).

Conditional inference tree analysis

In the conditional inference tree analysis, whirlpool sign, avascular nodule, and increased testicular vascularity were identified as significant discriminators of testicular torsion and other conditions of acute scrotum ($p<0.001$) (fig 1). The first split of the tree was made according to the whirlpool sign. The presence of a whirlpool sign regardless of testis vascularity led to node 7, in which all 31 patients had testicular torsion (100%, 31/31). In the other branch, which did not show the whirlpool sign, the next division was based on an avascular nodule at the superior pole of the testis. The presence of an avascular nodule led to node 6. Node 6 included 22 patients with appendage torsion (95.7%, 22/23). In the remaining 327 patients with no whirlpool sign and no avascular nodule, the next discriminator was increased testicular vascularity. The presence of increased testicular vascularity led to node 5, which included 39 patients with orchitis or epididymo-orchitis (81.2%, 39/48). On the opposite side of the decision tree, patients without increased testicular vascularity were classified into node 4, in which 255 patients (91.4%, 255/279) had epididymitis. All three patients with testicular torsion who were not included in node 7 (i.e., testicular torsion without whirlpool sign) were classified into node 4 (n=3) and had decreased vascularity (n=1) and avascularity (n=2) of the testis. Representative cases of the testicular torsion group are shown in fig 2 and 3.

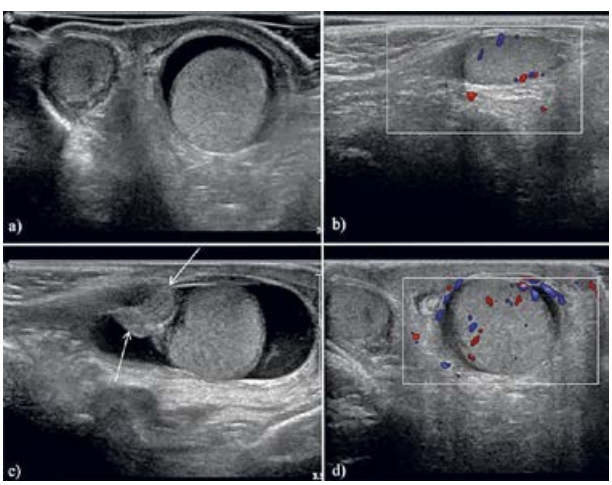

Fig 2. Gray-scale transverse US image of both testes (a), color Doppler longitudinal US image of the right testis (b) and gray-scale longitudinal (c) and color Doppler transverse (d) US images of the left testis in a 4-year-old boy with 4 h of acute left scrotal pain. An enlarged left testis with altered lie, whirlpool sign at the left spermatic cord (arrows), and an increased flow in the left testis compared with the right testis, can be observed.

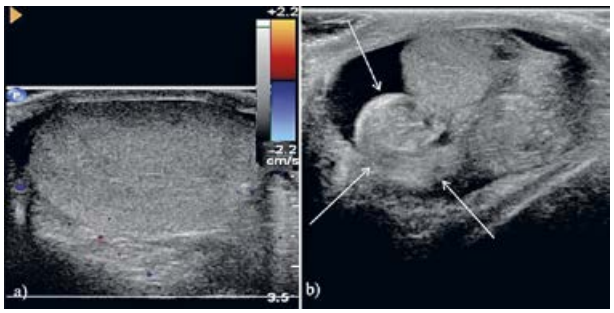

Fig 3. Color Doppler (a) and gray-scale longitudinal US image (b) of the left testis in a 14-year-old boy with acute left scrotal pain and swelling show absent vascularity of left testis and a whirlpool sign (arrows) at the left spermatic cord.

The accuracy of the conditional inference tree for the differential diagnosis of acute scrotum was 99.2% (95% confidence interval [CI], 97.7-99.8%) for testicular torsion, 92.4% (95% CI, 89.3-94.8%) for orchitis or epididymo-orchitis, and 99.2% (95% CI, 97.7-99.8%) for appendage torsion. The overall accuracy was 91.1% (95% CI, 87.8-93.7%).

Interobserver agreement

The interobserver agreement of the two radiologists was substantial to almost perfect for nine US findings, with Kappa values ranging from 0.685 to 1.000 (Table III).

Comparison of salvageable vs. non-salvageable testis in testicular torsion

Predictors of unsalvageable testis were evaluated in 21 patients, including 6 orchiectomy cases and 15 cases with orchiopexy, and available follow-up US. Among the 15 patients with orchiopexy, 8 showed atrophy of the involved testis on follow-up US (Supplementary Table I). As a result, 14 cases were considered non-salvaged (14/21, 67%). The symptom to operation time >24 h (p=0.001) and heterogeneous echotexture (p<0.001) were significantly different between the salvaged and non-salvaged testes (Table IV). Univariate analysis revealed that heterogeneous echotexture (odds ratio [OR], 74.99; 95% confidence interval [CI], 2.75-2046.26; p=0.01) and symptom-to-operation time >24 h (OR, 49.28; 95% CI, 1.92-1262.03; p=0.02) were significant predictors of unsalvageable testis (Table IV). A representative case of the non-salvaged group is shown in fig 4.

External validation of the diagnostic tree

In the external validation cohort, the accuracy of the conditional inference tree for the differential diagnosis of acute scrotum was 100% (95% confidence interval [CI], 96.6–100.0%) for testicular torsion, 95.3% (95% CI, 89.3–98.5%) for orchitis or epididymo-orchitis, 96.2% (95% CI, 90.6–99.0%) for epididymitis, and 99.1% (95%

Table II. Comparison of US imaging findings for acute scrotal diseases

		Testicular torsion	Orchitis or epididymo-orchitis	Epididymitis	Appendage torsion	p value†
Whirlpool sign	No	3 (8.8)	59 (100.0)	264 (100.0)	24 (100.0)	<0.001
	Yes	31 (91.2)	0 (0.0)	0 (0.0)	0 (0.0)	
Altered lie	No	28 (82.4)	59 (100.0)	264 (100.0)	24 (100.0)	<0.001
	Yes	6 (17.6)	0 (0.0)	0 (0.0)	0 (0.0)	
Volume ratio, mean±SD		1.43±0.62	1.09±0.26	1.08±0.26	1.06±0.25	<0.001
Heterogeneous echotexture	No	21 (61.8)	54 (91.5)	261 (98.9)	24 (100.0)	<0.001
	Yes	13 (38.2)	5 (8.5)	3 (1.1)	0 (0.0)	
Epididymal enlargement and/or hyperemia	No	30 (88.2)	23 (39.0)	164 (62.1)	12 (50.0)	<0.001
	Yes	4 (11.8)	36 (61.0)	100 (37.9)	12 (50.0)	
Normal vascularity	No	31 (91.2)	38 (64.4)	10 (3.8)	5 (20.8)	<0.001
	Yes	3 (8.8)	21 (35.6)	254 (96.2)	19 (79.2)	
Decreased vascularity	No	32 (94.1)	59 (100.0)	264 (100.0)	24 (100.0)	0.01
	Yes	2 (5.9)	0 (0.0)	0 (0.0)	0 (0.0)	
Avascularity	No	6 (17.6)	59 (100.0)	264 (100.0)	24 (100.0)	<0.001
	Yes	28 (82.4)	0 (0.0)	0 (0.0)	0 (0.0)	
Increased vascularity	No	33 (97.1)	20 (33.9)	255 (96.6)	19 (79.2)	<0.001
	Yes	1 (2.9)	39 (66.1)	9 (3.4)	5 (20.8)	
Avascular nodule	No	34 (100.0)	58 (98.3)	264 (100.0)	2 (8.3)	<0.001
	Yes	0 (0.0)	1 (1.7)	0 (0.0)	22 (91.7)	

Data are presented as number (percentage), except the volume ratio. †P value by one-way analysis of variance, Pearson's chi-square test, or Fisher's exact test as appropriate.

Table III. Interobserver agreement for US findings

Variables	Kappa value	95% confidence interval
Altered lie	0.855	0.655 to 1.000
Vascularity of testis		
– avascularity	0.961	0.908 to 1.000
– increased vascularity	0.685	0.573 to 0.798
– decreased vascularity	1.000	1.000 to 1.000
– symmetric and normal vascularity	0.756	0.674 to 0.839
Avascular nodule	0.867	0.761 to 0.972
Epididiymal enlargement and/or hyperemia	0.710	0.638 to 0.782
Heterogeneous echotexture	0.796	0.667 to 0.925
Whirlpool sign	0.934	0.869 to 0.998

CI, 94.9–100.0%) for appendage torsion. The overall accuracy of the conditional interference tree was 97.6% (95% CI, 95.7–98.9%).

Discussions

Many disease entities can cause acute scrotal pain such as testicular torsion, epididymitis, epididymo-orchitis, and appendage torsion in children and young adults [8,15]. In testicular torsion, the delayed diagnosis and treatment can lead to testicular ischemia, causing testicular necrosis and loss of testis, and US is the key imaging modality in the diagnosis. In our study, we aimed to create a schema that can emphasize key US features leading to differentiation between testicular torsion and various other common causes of acute scrotum. As a result, the most important discriminator was the "whirlpool sign" as the first criterion, followed by avascular nodule and increased testicular vascularity in our conditional inference tree analysis. We also studied the predictors of non-salvageable testes in patients diagnosed with testicular torsion. The presence of heterogeneous echotexture on US and time-to-operation time >24 h were significantly associated with testicular non-salvage.

In our conditional inference tree analysis, the whirlpool sign was selected as the first discriminator for the differential diagnosis of testicular torsion. Previous studies have noted the importance of the whirlpool sign for the diagnosis of testicular torsion. In the meta-analysis conducted in pediatric and adult patients, the pooled sensitivity and specificity of the whirlpool sign were 0.73 and 0.99, respectively for diagnosing testicular torsion by US [1]. In a prospective study by Vijayaraghavan et al [16], all 65 patients diagnosed with testicular torsion (complete 61, incomplete 4) had a whirlpool sign on initial US. The sensitivity and specificity of the whirlpool sign on testicular torsion were all 100%. The author emphasized that the whirlpool sign can be found anywhere along the spermatic cord from the inguinal canal to just around the testis; thus, full evaluation of the spermatic cord is important.

Absence of vascularity is well known finding of testicular torsion, and it can be easily detected on US, but it has some limitations. Kalfa et al [17] studied the sensitivity and specificity of testicular vascularity and whirlpool sign on US in 208 children. Of the patients confirmed to have testicular torsion by surgery, spiral twisting of the spermatic cord was found in 199/208 patients, resulting in a sensitivity of 99%, while the absence of vascularity on Doppler US was observed in 158/208 (sensitivity 76%). Moreover, if a linear spermatic cord without twisting was observed on US, other diseases occupied most causes of scrotal pain, resulting in a whirlpool sign specificity of 99% (705/711). The sensitivity of absence of vascularity can be lower than that of the whirlpool sign, because intratesticular vascularity can be preserved in some cases: (1) in cases of partial or incomplete torsion, the spermatic cord twists less than 360°and it enables perfusion to the testis; (2) in torsion-detorsion or intermittent torsion, the

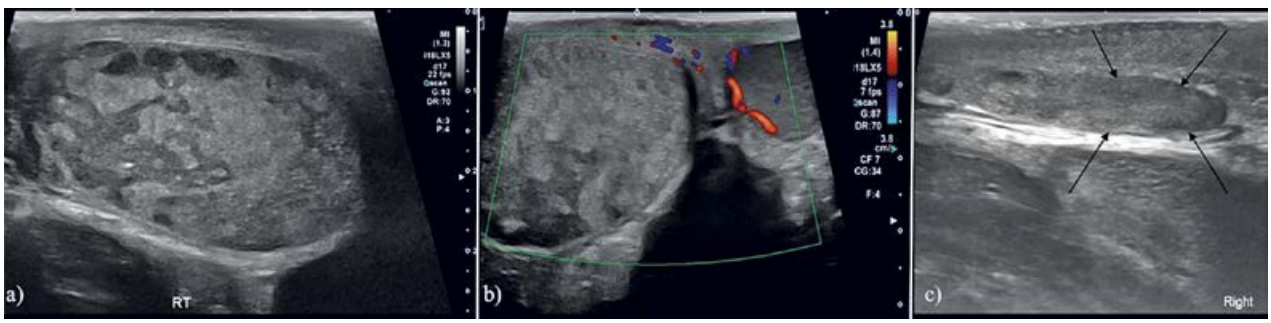

Fig 4. Gray-scale longitudinal US image of the right testis (a) and color Doppler longitudinal US image of both testes (b) in a 15-year-old boy with 2 days of acute right scrotal pain show markedly heterogeneous parenchymal echogenicity and absence of flow in the right testis. He underwent orchiopexy, and follow-up US after 6 months shows atrophy of the right testis (arrows) (c).

Table IV. Comparison of salvageable vs. non-salvageable testis in testicular torsion

		Salvage	Non-salvage	p value†	Univariate logistic regression	
					Odds ratio (95% CI)‡	p value†
N		7	14			
Age, mean±SD (year)		14.14±2.85	12.14±7.50	0.3911	0.96 (0.82-1.11)	0.56
Side of symptom	Right	1 (14.3)	1 (7.1)	1.0000	1 (Ref)	0.63
	Left	6 (85.7)	13 (92.9)		2.08 (0.11-39.02)	
Symptom onset to operation >24 h	No	7 (100.0)	3 (21.4)	0.001	1 (Ref)	0.02
	Yes	0 (0.0)	11 (78.6)		49.28 (1.92-1262.03)	
Whirlpool sign	No	0 (0.0)	1 (7.1)	>0.999	1 (Ref)	0.82
	Yes	7 (100.0)	13 (92.9)		0.59 (0.01-60.88)	
Altered lie	No	5 (71.4)	10 (71.4)	>0.999	1 (Ref)	0.95
	Yes	2 (28.6)	4 (28.6)		0.94 (0.13-6.83)	
Volume ratio, mean±SD		1.19±0.27	1.66±0.83	0.07	3.12 (0.44-21.94)	0.25
Heterogeneous echotexture	No	7 (100.0)	2 (14.3)	<0.001	1 (Ref)	0.01
	Yes	0 (0.0)	12 (85.7)		74.99 (2.75-2046.26)	
Epididymal enlargement and/or hyperemia	No	7 (100.0)	10 (71.4)	0.26	1 (Ref)	0.28
	Yes	0 (0.0)	4 (28.6)		6.43 (0.21-193.84)	
Normal vascularity	No	5 (71.4)	14 (100.0)	>0.999	1 (Ref)	0.19
	Yes	2 (28.6)	0 (0.0)		0.08 (0.00-3.57)	
Decreased vascularity	No	6 (85.7)	13 (92.9)	>0.999	1 (Ref)	0.63
	Yes	1 (14.3)	1 (7.1)		0.48 (0.03-9.05)	
Avascularity	No	3 (42.9)	2 (14.3)	0.28	1 (Ref)	0.20
	Yes	4 (57.1)	12 (85.7)		3.89 (0.48-31.64)	
Increased vascularity	No	7 (100.0)	13 (92.9)	>0.999	1 (Ref)	0.82
	Yes	0 (0.0)	1 (7.1)		1.72 (0.02-180.11)	

Data are presented as numbers (percentages), except for age and volume ratio. †p value by Student's t-test or Fisher's exact test, as appropriate. ‡Logistic regression with Firth's penalized maximum-likelihood method.

spermatic cord twists in a short duration, but resolves spontaneously; (3) torsion-detorsion status can also allow compensatory hypervascularity sometimes, which can mimic inflammation [11,15]. These findings can lead to false-negative diagnoses in patients with testicular torsion. In our study, three patients and one patient in the testicular torsion group showed normal and increased vascularity of the testis, respectively. However, all patients in the testicular torsion group who did not show the whirlpool sign had decreased vascularity or avascularity of the testis on US. Therefore, we assume that the absence of vascularity on Doppler US can be helpful as a supportive feature, particularly when torsion knot is not detected. Considering in combination the whirlpool sign as the first step and absence of vascularity would enable the most accurate diagnosis of testicular torsion by US and would help avoid misdiagnosis in testicular torsion with preserved flow. Similarly, a previous study showed that evaluation of both the whirlpool sign of the spermatic cord and testicular vascularity not only improves sensitivity in the diagnosis of testicular torsion, but also reduces the gap between junior and senior radiologists [17].

Torsion of the testicular appendage is an important differential diagnosis of testicular torsion. In our study, patients with appendage torsion were younger than those with other causes of acute scrotum, consistent with previous studies [18,19]. The reported US findings of appendage torsion are avascular, enlarged appendix with inflammatory reaction, and increased flow in nearby structures [20]. In the conditional inference tree analysis, avascular nodule was selected as the second discriminator for the differential diagnosis of acute scrotum, which was helpful in ruling out appendage torsion. The overall accuracy of our simplified decision tree model was high, and the accuracy of the less-experienced radiologist in the external validation cohort was also high. The application of this tree model would be helpful for different levels of operators from radiology trainees or clinicians to senior radiologists in diagnosing testicular torsion more accurately.

Our result is consistent with previous studies that reported heterogeneous echotexture and a longer time interval to surgery were significant predictors of testicular non-salvage. In the study by Kaye et al [4], of the 55

patients who were diagnosed with testicular torsion, 37 showed heterogeneous echotexture on preoperative US. Their pathologies revealed necrosis, and the testes were non-viable. On the other hand, of the 18 patients who showed a homogeneous echotexture, only two had necrosis and their testes were not salvaged. Grimsby et al [3] prospectively studied the predictors of testicular viability. In patients who underwent orchiopexy for testicular torsion, they found that pain duration >12 h, heterogeneity of the testicular parenchyma on US, and intraoperative testicular visual color (black and hemorrhagic/necrotic testicle) are associated with testicular atrophy on follow-up US. According to the study by Blask et al, epididymal swelling can be seen in up to 94% of testicular torsion patients; however, our study showed epididymal enlargement in only 12% in testicular torsion cases. It is possible that observers in our study recognized epididymal-cord complex as a twisting torsion knot and could not distinguish epididymis from the torsion knot in some cases of testicular torsion when reviewing saved US images on the PACS.

This study has several limitations. It was a retrospective study, and testicular volume could not be evaluated on follow-up US in all patients who underwent orchiopexy, which led to an unintended selection bias. In addition, clinical information such as onset of form, degree and duration of pain, and presence of Prehn's sign could be helpful in differential diagnosis of testicular torsion and other diseases. However, we could not analyze clinical signs and symptoms due to our study's retrospective design. Instead, we created a decision tree model focusing on US variables useful for acute scrotum. Second, several operators performed US in this study, which could affect the results depending on the operator's experience and skills. However, in real-world practice, most patients with scrotal pain mainly visit the emergency room, and US imaging by multiple operators (usually on-call radiologists) is unavoidable. Moreover, we assessed interobserver agreement between a resident in trainee and a pediatric radiologist in terms of evaluating US features on PACS images, and the results showed substantial to perfect agreement. Third, the final diagnosis of some causes of acute scrotum are influenced by US findings and it can raise questions about the usefulness of the diagnostic tree model. US is a part of diagnostic approach which may not always provides positive information, and impression in US report is not necessarily same with the final diagnosis in some cases. Moreover, considering US results to make the diagnosis is a practical way especially in patients with unclear clinical symptoms. Despite these limitations, a simplified conditional tree model suggested in this study would be helpful for deferent levels of operators in differentiating various causes of acute scrotum.

In **conclusion**, to differentiate testicular torsion and other common diseases of the acute scrotum, we recommend evaluating the presence of the whirlpool sign as a first step. Evaluation of decreased or absence of vascularity of the testis can minimize the risk of false-negative US diagnosis in patients with testicular torsion. The presence of avascular nodules and increased testicular vascularity were significant discriminators in the conditional inference tree model to rule out other causes of acute scrotum. Moreover, heterogeneous echotexture was the most important prognostic factor for unsalvageable testes on US.

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