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Original Article

Clinical value of shear wave elastography (SWE) combined with superb microvascular imaging (SMI) for the evaluation of semen abnormalities

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Abstract: Objective: To investigate the clinical value of shear wave elastography (SWE) and superb microvascular imaging (SMI) in patients with semen abnormalities. Methods: A total of 150 patients with abnormal semen parameters who were treated at the Reproductive Center of the Affiliated Hospital of Putian University between January 2024 and December 2025 were retrospectively enrolled as the case group. In addition, 100 healthy individuals aged 18-35 were selected as the control group. SWE and SMI examinations were performed in both groups. Testicular volume and semen quality parameters were also measured. The diagnostic performance of SWE and SMI for semen abnormalities was evaluated using receiver operating characteristic (ROC) curve analysis. Spearman correlation analysis and one-way analysis of variance (ANOVA) were used to assess the correlation between SWE/SMI parameters and semen quality. Results: Bilateral testicular shear wave elastography values in the control group were significantly lower than thsoe in the case group (both P<0.05). Bilateral microvascular grading based on SMI was significantly lower in the case group than the control group (χ^2=153.344, 160.346, P<0.05). LTSWE was significantly negatively correlated with left testicular volume, sperm concentration, total sperm count, semen volume, and total sperm motility (P<0.05). Right testicular shear wave elastography (RTSWE) was significantly negatively correlated with total sperm motility. The area under the ROC curve (AUC) for LTSWE and RTSWE in diagnosing semen abnormalities was 0.805 and 0.626, respectively, while the combined AUC was 0.814. Left testicular SMI microvascular grading was related to LTSWE, total sperm count, and total sperm motility (P<0.05). Right SMI microvascular grading was associated with RTSWE, sperm concentration, total sperm count, and total sperm motility (P<0.05). The sensitivity and specificity of SMI in diagnosing semen abnormalities were 83.33% and 96.0%, respectively. When combined with TSWE, the sensitivity and specificity increased to 87.33% and 99.0%, respectively. Conclusion: SWE and SMI are associated with semen quality parameters and demonstrate diagnostic value for semen abnormalities.

Keywords: Shear wave elastography, superb microvascular imaging, semen, abnormal

Introduction

In China, about 10% of married couples experience infertility, with male factors accounting for nearly 40% [1, 2]. Previous studies have shown that the etiology of male infertility remains incompletely understood and may be related to multiple factors, including hormonal imbalances of the hypothalamic-pituitary-gonadal axis affecting testicular spermatogenesis, congenital testicular developmental abnormalities, and obstruction of sperm transport pathways [2-4]. At present, there is no effective noninvasive method for evaluating oligoasthenozoospermia. Although traditional testicular biopsy can directly assess spermatogenic function, its invasive nature limits patients acceptance in clinical practice.

With the continuous development of ultrasound imaging techniques, conventional color Doppler ultrasound has demonstrated multiple advantages in testicular evaluation, including low cost, convenience, dynamic observation, bilateral comparison, and ease of follow-up, thereby providing important support for clinical diagnosis and treatment.

Shear Wave Elastography (SWE) is an emerging elastography technique that quantifies tissue

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stiffness by measuring the propagation velocity of shear waves generated by acoustic radiation force impulses. SWE has been widely applied in the evaluation of thyroid, breast, and prostate nodules, placental function, joint disease, and hepatic fibrosis; in addition, it has also shown diagnostic value in conditions such as cryptorchidism, testicular microlithiasis, scrotal effusion, testicular torsion, and testicular tumors [5-7]. Although its application has been extended to other anatomical regions, there are few reports on its application in scrotal pathology [8, 9].

Superb microvascular imaging (SMI) is a novel Doppler ultrasound technique that enables high-resolution visualization of low-speed blood flow by using advanced clutter suppression algorithms combined with high frame rates and low velocity thresholds. It effectively reduces motion artifacts while preserving low-flow vascular signals, thereby overcoming the shortcomings of insufficient sensitivity to microvascular perfusion. Therefore, it significantly enhances the detection of low-speed blood flow in small blood vessels [10]. This allows a more comprehensive assessment of intratesticular microcirculation. Therefore, the use of microvascular imaging in evaluating spermatogenic function is considered both theoretically and technically feasible, and has great potential for application.

This study aims to investigate the reliability and clinical value of SWE and SMI in patients with semen abnormalities, and to provide imaging-based evidence to support the diagnosis and management of semen abnormalities.

Materials and methods

General information of the subjects

A retrospective study was conducted on 150 male patients who were diagnosed with abnormal semen parameters according to the World Health Organization (WHO) standards based on semen analysis and treated at the Reproductive Center of the Affiliated Hospital of Putian University between January 2024 and December 2025. In addition, 100 healthy individuals aged 22-45 years who underwent scrotal ultrasonography and laboratory semen screening without any significant abnormalities were selected as the control group. This study was reviewed and approved by the Medical Ethics Committee of the Affiliated Hospital of Putian University (Approval Number: 2026012).

Inclusion criteria: (1) Male patients aged 22-45 years; (2) Patients who met the WHO diagnostic criteria for semen abnormalities; (3) No history of medication affecting semen quality within the past 2 weeks.

Exclusion criteria: (1) Presence of testicular or epididymal tumors or inflammatory lesions; (2) Congenital or acquired abnormalities in testicular morphology, size, or epididymal structure; (3) Presence of servere systemic diseases involving major organs; (4) History of psychiatric disorders or cognitive impairment; (5) History of urogenital surgery that may affect semen quality, such as testicular resection; (6) History of medication use known to affect semen quality, inclduing antibiotics, diuretics, beta blockers, and anticancer drugs.

Shear wave elastography technology

SWE measurements were performed using an Aplio i800 Platinum ultrasound system (Canon, Tokyo, Japan) with a high-frequency linear array transducer (11-14 MHz). The patient was placed in a supine position, and the scrotum was fully exposed. The patient was instructed to gently lift the penis and secure it against the anterior abdominal wall. After obtaining a clear longitudinal view of the testis, the system was switched to the elastography mode. The transducer (L14-5WU) was placed gently and perpendicular to the testicular surface. Patients were instructed to hold their breath to minimize motion artifacts.

Once the image stabilized, SWE was activated. A circular region of interest (ROI) with a diameter of 10 mm was placed in the center region of the testis, avoiding the tunica albuginea and other high-stiffness peripheral structures to minimize measurement bias. Each measurement was repeated three times at the same location, and the mean value was calculated and recorded as the Young's modulus of the testis, expressed in KPa.

Superb microvascular imaging examination

SMI examination were performed using the same Aplio i800 platinum ultrasound system

(Canon Medical Systems, Tokyo, Japan), equipped with an SMI software module and a high-frequency linear probe (11L4, 4.8-10.0 MHz). Following the selection of SMI mode, imaging parameters - including the sampling box size, velocity scale, and color gain - were adjusted to optimize visualization of microvascular flow. The area of interest for vascular index was drawn and the coexisting results of vascular index VI were displayed. Further observation and analysis of SMI images and vascular indices were performed.

Intratesticular blood flow was further classified into grade 0-3 according to the Adler grading system [26-28]. Grade 0: no detectable intratesticular blood flow; Grade 1: 1-2 punctate vascular signals; Grade 2: scattered or linear vascular signals; Grade 3: Clear branching vascular network. Conventional color Doppler flow imaging (CDFI) and SMI findings were independently evaluated. For SMI assessment, abnormal testicular perfusion was defined as a significant reduction or complete disappearance of intratesticular blood flow signals.

Observation indicators

(1) According to the WHO guidelines, all patients were instructed to abstain from sexual activity for 5-7 days prior to semen collection. Semen samples were obtained via masturbation in a quiet collection room and sent for testing within 30 minutes at room temperature. Semen parameters were assessed using an automatic semen analyzer, including sperm count, sperm concentration, total sperm motility, progressive motility (PR), and non-progressive motility (NP).

(2) Serum reproductive hormone levels were measured using chemiluminescence immunoassay, including luteinizing hormone (LH), follicle stimulating hormone (FSH), prolactin (PRL), estradiol (E2), and testosterone (T).

(3) Left and right testicular shear wave elastography (LTSWE/RTSWE) values and Adler grading were recorded for both groups.

Statistical analysis

SPSS 26.0 software (IBM, Ammonk, New York, USA) was used for statistical analyses. Normality of continuous variables was assessed prior to analysis. Continuous variables conforming to a normal distribution were expressed as mean ± standard deviation (Mean ± SD), and inter-group comparisons were performed using the independent sample t-test. Non-normally distributed continuous variables were presented as median (interquartile range, M [P25, P75]) and compared between groups using Mann-Whitney U test. Categorical variables were expressed as n (%) and analyzed using the chi-square test or Fisher's exact test, as appropriate.

Spearman correlation analysis was used to assess the correlation between SWE parameters, SMI grading, and semen-related indices. Receiver operating characteristic (ROC) curve analysis was performed to evaluate the diagnostic performance of SWE and SMI in identifying patients with semen abnormalities. A two-sided P value <0.05 was considered statistically significant.

Results

Comparison of baseline characteristics, testicular volume, and semen parameters between the two groups

There were no significant differences in age or BMI between the case and control groups (P>0.05). The incidence of varicocele in the case group was significantly higher than that in the control group. (χ^2=121.614, P<0.001) (**Table 1**).

No significant difference was observed in right testicular volume between the two groups (P>0.05). However, semen volume and total sperm count in the case group were significantly lower than those in the control group (Z=-11.588, -2.127; P<0.001, P=0.033). Left testicular volume, sperm concentration, and total sperm motility in the case group were significantly lower than those in the control group (t=8.082, 6.731, 34.746, P<0.001). (**Table 1**).

Comparison of reproductive hormone levels between the two groups

Serum T levels in the case group were significantly lower than that in the control group (t=10.000, P<0.05), while FSH and LH levels in the case group were significantly higher than those in the control group (Z=-12.154, -8.495, P<0.05). No significant differences were ob-

Table 1. Comparison of baseline information between the two groups

Index	control group (n=100)	case group (n=150)	t/Z/χ^2	*P*
Age (years)	28.93±4.55	29.24±4.05	-0.551	0.582
BMI (kg/m^2)	27.98±7.65	26.95±6.53	1.021	0.091
Varicocele			121.614	<0.001
Yes	11	123		
No	89	27		
Testicular volume (mL)				
left side	15.08±1.63	13.44±1.53	8.082	<0.001
right side	14.74±1.35	14.71±1.10	0.177	0.860
semen volume (mL)	3.01 (2.64, 3.91)	2.01 (1.78, 2.24)	-11.588	<0.001
sperm concentration (10^6/mL)	60.71±8.52	43.48±29.55	6.731	<0.001
Total sperm motility (%)	65.77±7.91	20.28±12.78	34.746	<0.001
Total sperm count (10^6/time)	142.00 (60.00, 163.00)	77.35 (34.68, 170.83)	-2.127	0.033
Varicocele			143.128	<0.001
Yes	10	130		
No	90	20		
T (ng/L)	4.89±0.60	3.44±1.36	10.000	<0.001
PRL (ng/L)	6.68±1.32	6.89±0.63	-1.513	0.133
FSH (mIU/mL)	7.00 (6.57, 7.58)	13.43 (12.21, 14.13)	-12.154	<0.001
E2 (pg/mL)	34.13 (26.00, 34.98)	29.85 (27.72, 32.36)	-1.362	0.173
LH (mIU/mL)	4.99 (3.39, 5.97)	6.50 (5.57, 7.31)	-8.495	<0.001

Notes: BMI: Body Mass index; T: testosterone; FSH: Follicle stimulating hormone; PRL: prolactin; E2: estradiol; LH: Luteinizing hormone.

served in PRL or E2 levels between the two groups (*P*>0.05) (**Table 1**).

Comparison of testicular shear wave elastography and microvascular grading between the two groups

Both LTSWE and RTSWE values were significantly higher in the case group than the control group (t=-10.831, -5.258, P<0.05) (**Table 2**). In contrast, bilateral testicular microvascular grading based on SMI was significantly lower in the case group compared with the control group (χ^2=153.344, 160.346, *P*<0.05) (**Table 2**).

Correlation between SWE, semen parameters, and reproductive hormone levels in the case group

In the case group, LTSWE was significantly negatively correlated with left testicular volume, semen volume, sperm concentration, total sperm count, and total sperm motility (*P*<0.05) (**Table 3**; **Figure 1A-E**). RTSWE was significantly negatively correlated with total sperm motility, but not significantly correlated with testicular volume, semen volume, total sperm count, or sperm concentration (**Table 3**; **Figure 1F**).

Regarding reproductive hormones, LTSWE was significantly negatively correlated with T and significantly positively correlated with FSH and E2 (*P*<0.05, **Table 3**; **Figure 2**). No significant correlations were observed between LTSWE and PRL or LH. Additionally, RTSWE demonstrated no significant correlation with any of the measured reproductive hormones (*P*>0.05).

Diagnostic efficacy of TSWE for semen abnormalities

The AUC of LTSWE for diagnosing semen abnormalities was 0.805, with a sensitivity of 66.7% and specificity of 96.0% (**Figure 3A**). The AUC of RTSWE for diagnosing semen abnormalities was 0.626, with a sensitivity of 34.7% and specificity of 86.0% (**Figure 3B**). The combined model of LTSWE and RTSWE yielded an AUC of 0.814, with a sensitivity of 67.3% and specificity of 99.3% (**Figure 3C**).

Delong test showed significant differences between the AUC of RTSWE and LTSWE, as well

Table 2. Comparison of testicular SWE parameters and SMI grading between the two groups

Index	control group (n=100)	case group (n=150)	t/χ^2	*P*
Testicular SEE value (kPa)				
LTSWE	4.49±0.39	5.21±0.65	-10.831	<0.001
RTSWE	4.46±0.39	4.85±0.76	-5.258	<0.001
Adler blood flow grading (Left testicle)			153.344	<0.001
Grade 0	1	8		
Grade I	2	113		
Grade II	33	20		
Grade III	64	9		
Adler blood flow grading (Right testicle)			160.346	<0.001
Grade 0	1	5		
Grade I	1	113		
Grade II	37	28		
Grade III	61	4		

Notes: SMI: superb microvascular imaging; LTSWE: Left testicular shear wave elastography; RTSWE: Right testicular shear wave elastography.

Table 3. Correlation between bilateral testicular SWE values and testicular volume and sperm quality in case group

Index	LTSWE		RTSWE	
	r	*P*	r	*P*
Left testicular volume	-0.248	0.002	-	-
Right testicular volume	-	-	0.133	0.105
Semen volume	-0.164	0.045	-0.049	0.554
Sperm concentration	-0.312	<0.001	-0.095	0.249
Total sperm count	-0.298	<0.001	-0.148	0.070
Total sperm motility	-0.327	<0.001	-0.265	0.001
T	-0.172	0.035	0.087	0.291
PRL	-0.087	0.291	0.160	0.051
FSH	0.293	<0.001	0.004	0.958
E2	0.250	0.002	0.112	0.171
LH	0.070	0.398	0.149	0.069

Notes: LTSWE: left testicular shear elastography; RTSWE: right testicular shear elastography; T: testosterone; FSH: Follicle stimulating hormone; PRL: prolactin; E2: estradiol; LH: Luteinizing hormone.

as between RTSWE and the combined model (Z=4.212, -5.195, *P*<0.001). No significant difference was observed in AUC between LTSWE and the combined model (Z=-0.830, P=0.407).

Predictive value of TSWE for abnormal sperm concentration, total sperm count, and total sperm motility

For TSWE, the AUC for predicting abnormal sperm concentration was 0.614, with a sensitivity of 43.7% and specificity of 79.2% (**Figure 4A**); the AUC for predicting abnormal sperm count was 0.605, with a sensitivity of 68.3% and specificity of 56.0% (**Figure 4B**); the AUC for predicting abnormal total sperm motility was 0.678, with a sensitivity of 61.8% and specificity of 69.8% (**Figure 4C**). The AUC for RTSWE in predicting abnormal total sperm motility was 0.629, with a sensitivity of 57.9% and specificity of 66.7% (**Figure 4D**).

The correlation between SMI blood flow grading, TSWE, and semen quality

Left testicular SMI microvascular grading was significantly associated with LTSWE, total sperm count, and total sperm motility (*P*<0.05), but showed no significant association with testicular volume, semen volume, or sperm concentration (*P*>0.05). LTSWE values in SMI grade 0 and grade 1 cases were significantly higher than those in grade 3 (*P*<0.05, **Figure 5**). Total sperm count in grade 0 and 1 was significantly lower than that in grade 2 (*P*<0.05). Total sperm motility in grade 0 and grade 1 was significantly lower than that in grade 2 and grade 3 (*P*<0.05).

Right SMI microvascular grading was significantly associated with RTSWE, sperm concentration, total sperm count, and total sperm motility (*P*<0.05, **Figure 6**). RTSWE values in grade 0 and grade 1 cases were significantly

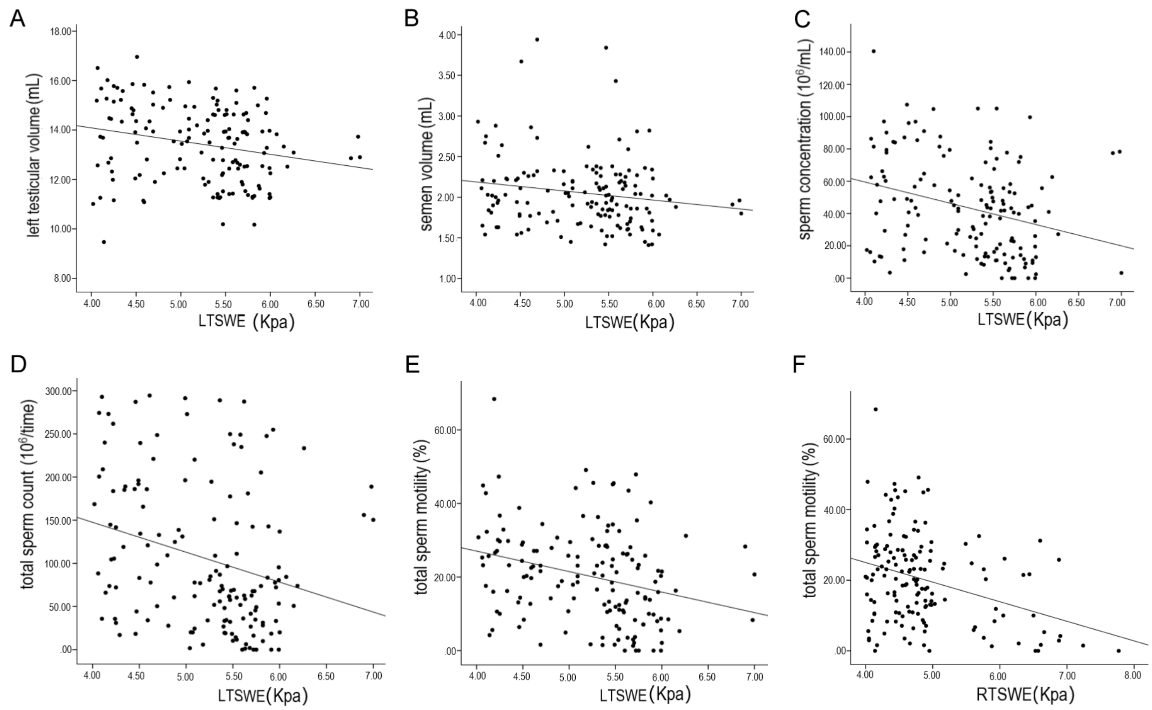

Figure 1. Correlation between RTSWE, LTSWE and semen quality. A: The correlation between LTSWE and left testicular volume. B: The correlation between LTSWE and semen volume. C: The correlation between LTSWE and sperm concentration. D: The correlation between LTSWE and total sperm count. E: The correlation between LTSWE and total sperm motility. F: The correlation between RTSWE and semen quality. Notes: RTSWE: right testicle shear wave elastic modulus; LTSWE: left testicle shear wave elastic modulus.

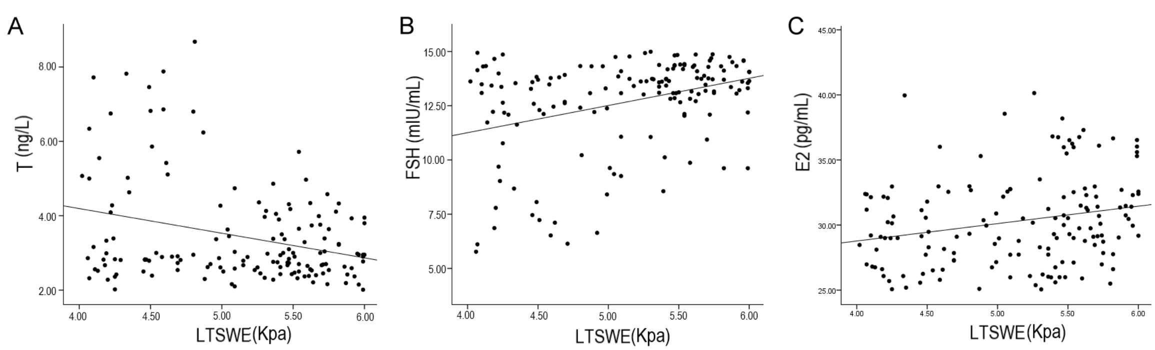

Figure 2. Correlation between TSWE value and reproductive hormone level. A: The correlation between LTSWE and T. B: The correlation between LTSWE and FSH. C: The correlation between LTSWE and E2. Notes: LTSWE: left testicle shear wave elastography; T: testosterone; FSH: Follicle-Stimulating Hormone; E2: Estradiol.

higher than those in grade 2 (P<0.05). Sperm concentration in grade 0 was significantly lower than that in grades 2 and 3 (P<0.05). Total sperm count in grade 0 was significantly lower than that in grades 1 and 2 (P<0.05). In addition, total sperm motility in grade 0 and grade 1 was significantly lower than that in grades 2 and 3 (P<0.05). There was no significant correlation between bilateral SMI microvascular grading and reproductive hormone levels (both P>0.05).

Diagnostic value of SWI for semen abnormalities

The diagnostic value of SWI for semen abnormalities is shown in **Table 4**. SMI alone demonstrated a sensitivity of 83.33% (125/150),

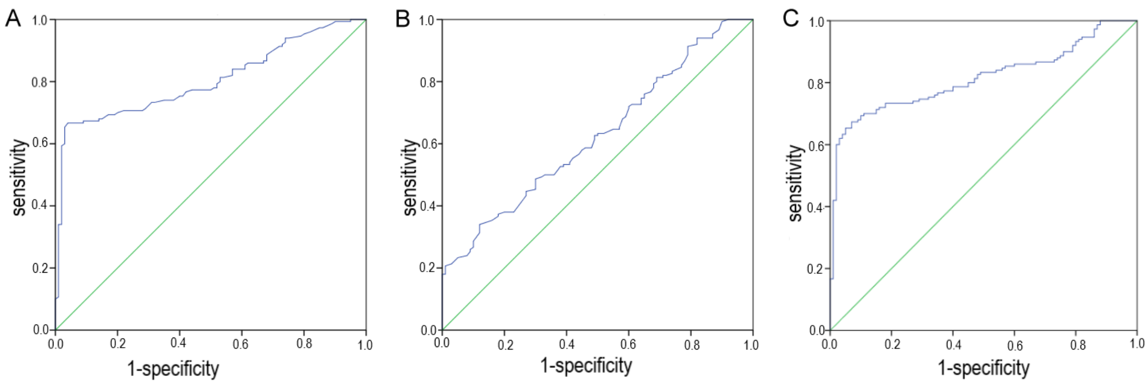

Figure 3. ROC curves for LTSWE and RTSWE in diagnosing semen abnormalities. A: ROC curve for LTSWE in diagnosing semen abnormalities. B: ROC curves for RTSWE in diagnosing semen abnormalities. C: ROC curve for LTSW combined with RTSWE in diagnosing semen abnormalities. Notes: RTSWE: right testicle shear wave elastography; LTSWE: left testicle shear wave elastography.

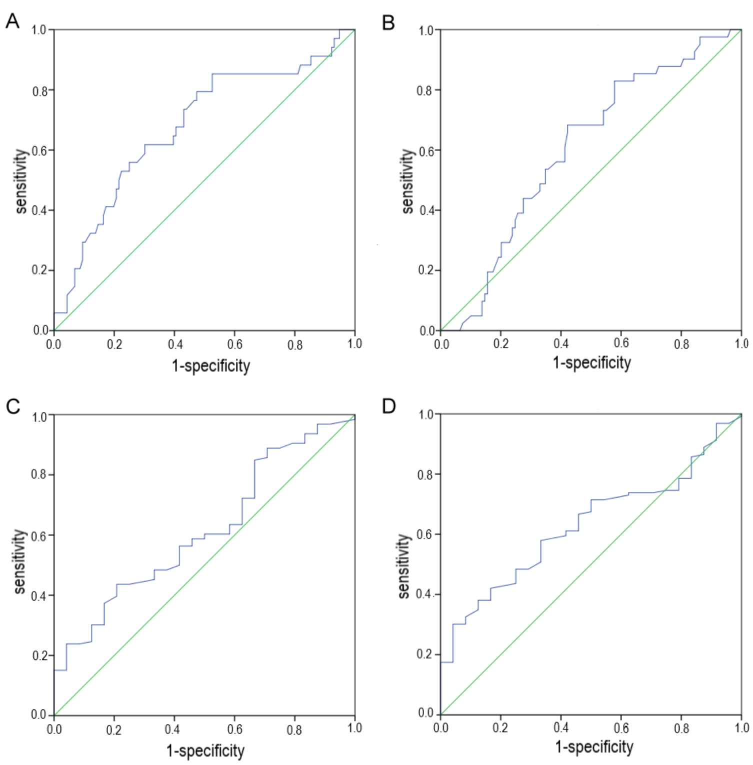

Figure 4. ROC curves for LTSW and RTSWE in evaluating sperm concentration, total sperm count, and total sperm motility. A: ROC curve for LTSW in evaluating sperm concentration. B: ROC curve of LTSW in evaluating total sperm count. C: ROC curve of LTSW in evaluating total sperm motility. D: ROC curve of RLTSW in evaluating total sperm motility. Notes: RTSWE: right testicle shear wave elastography; LTSWE: left testicle shear wave elastography.

specificity of 96.0% (96/100), and accuracy of 88.4% (221/250). When combined with TSWE, the sensitivity increased to 87.33% (131/150), specificity to 99.0% (99/100), and overall accuracy to 92.0% (230/250).

Discussion

The pathogenic mechanisms of male infertility remain incompletely understood and may be related to multiple factors, including endocrine imbalance of the hypothalamic-pituitary-gonadal axis affecting testicular spermatogenesis, congenital testicular developmental abnormalities, and obstruction of sperm transport pathways [11, 12]. The comprehensive evaluation of testicular pathology relies on the assessment of intratesticular blood flow distribution and hemodynamic characteristics, which play an essential role in the diagnosis of testicular diseases. With the increasing detection rate of male infertility, the clinical demand for color Doppler ultrasonography to objectively display testicular blood flow and indirectly reflect spermatogenic function are growing [13]. However, conventional Doppler techniques have limited sensitivity in detecting small-caliber and low-velocity microvessels, which limits their application in

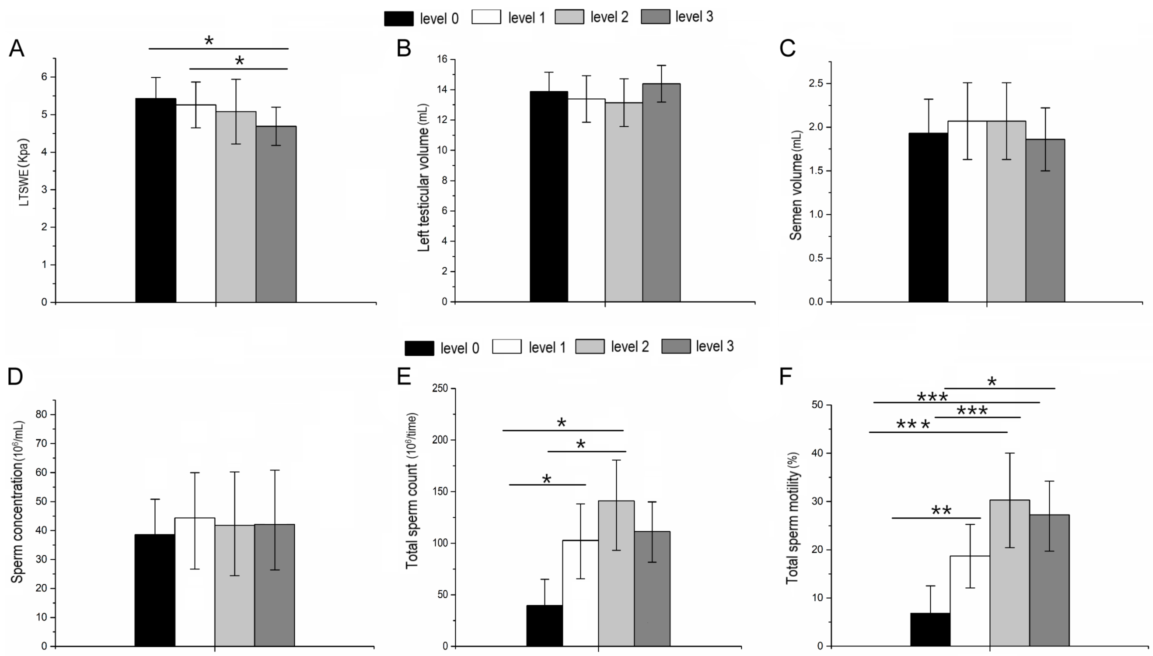

Figure 5. Correlation between left testicular SMI grading and semen quality. A: The correlation between SMI grading and LTSWE. B: The correlation between SMI grading and left testicular volume. C: The correlation between SMI grading and semen volume. D: The correlation between SMI grading and sperm concentration. E: The correlation between SMI grading and total sperm count. F: The correlation between SMI grading and total sperm motility. Notes: SMI: superb microvascular imaging; LTSWE: left testicle shear wave elastography. *P<0.05, **P<0.01, ***P<0.001.

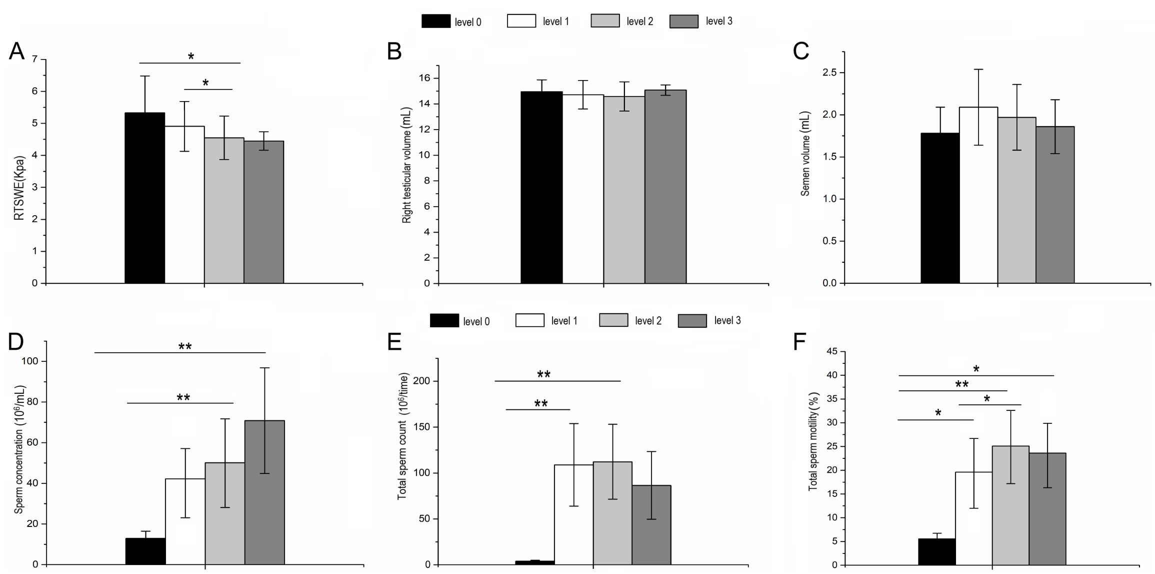

Figure 6. Correlation between right testicular SMI grading and semen quality. A: The correlation between blood flow grading and RTSWE. B: The correlation between blood flow grading and left testicular volume. C: The correlation between blood flow grading and semen volume. D: The correlation between blood flow grading and sperm concentration. E: The correlation between blood flow grading and total sperm count. F: The correlation between blood flow grading and total sperm motility. Notes: SMI: superb microvascular imaging; RTSWE: right testicle shear wave elastography. *P<0.05, **P<0.01.

Table 4. Diagnostic accuracy of SMI grading and TSWE versus WHO gold standard for semen abnormalities

Inspection method	Inspection results	Gold standard		Total
		+	-	
SMI	+	125	4	129
	-	25	96	121
SMI combined with SWE	+	131	1	132
	-	19	99	118

Notes: SWI: superb microvascular imaging; SWE: shear wave elastography.

evaluating subtle testicular microcirculatory changes. Therefore, there is an urgent need to develop simple and reliable diagnostic methods for assessing spermatogenic function in patients with oligozoospermia and asthenospermia.

In recent years, ultrasound elastography (UE) has gained increasing attention in the evaluation of male infertility. Histopathological studies have shown that tissue elasticity is related to underlying biological and structural characteristics, with significant differences in stiffness between normal and diseased testicular tissues. SWE quantitatively measures the elasticity of tissues or organs by measuring the propagation velocity of shear waves generated by acoustic radiation force. In this process, shear stress refers to force applied parallel to the tissue surface, accompanied by an opposing force on the opposite plane [14-16]. Research has shown that SWE can effectively evaluate testicular stiffness in patients with varicocele and predict the severity of testicular parenchymal damage [17-19]. Erdogan et al. also reported that the testicular SWE values were significantly higher in affected testes compared with normal testes in patients with varicocele [20]. Similarly, the present study demonstrated that the incidence of varicocele in patients with abnormal semen parameters was 86.67%, and significant differences in TSWE were observed between patients and healthy controls.

TSWE demonstrated good diagnostic performance for semen abnormalities, with an AUC of 0.814, sensitivity of 67.3%, and specificity of 99.3%, respectively. In addition, TSWE was significantly correlated with total sperm count, sperm concentration, and total sperm motility in patients with abnormal semen parameters. However, previous studies have reported inconsistent findings that there was no significant correlation between SWE values and varicocele or testicular volume [21]. These discrepancies may be attributed to heterogeneity in study populations, and therefore, further large-scale and multicenter studies are required to validate the diagnostic performance of SWE in predicting testicular parenchymal injury. Overall, SWE provides a quantitative and noninvasive method for detecting subtle changes in testicular tissue stiffness. It may serve as a powerful tool for evaluating testicular injury and has potential diagnostic value in identifying semen abnormalities. Additionally, SWE may also provide supplementary imaging evidence for the early diagnosis of varicocele.

SMI is a novel Doppler ultrasound technique developed to overcome the limitations of conventional Doppler systems associated with wall filters setting. Compared with color Doppler imaging (CDI), power Doppler imaging (PDI), and color microvascular imaging techniques, monochromatic ultra-high microvascular imaging is significantly superior in displaying cryptorchidism blood vessels. In addition, compared to the contralateral normal testis, the blood flow of cryptorchidism is significantly lower [22, 23]. Ates et al. [24] reported that both testicular volume and 2D-cSMI vascular index value on the varicocele-affected side were significantly lower than those of the contralateral healthy testis. Similarly, Ayaz et al. neonatal testicular blood flow assessment using SMI was superior to conventional Doppler techniques, with diagnostic performance ranking as follows: mSMI>PDI>CDI>ADF.

Pathological changes such as epithelial cell calcification and deposition in the seminiferous tubules may lead to tubular obstruction and impaired microcirculation, which are often undetectable by conventional ultrasound techniques [25]. Therefore, SMI may provide a more accurate assessment of testicular microvascular integrity and serve as an indirect imaging marker of spermatogenic function.

In addition, SMI grading was applied to evaluate intratesticular perfusion in this study. Grade 0 indicates the absence of detectable microvascular signals within the testicular parenchyma, suggesting severe ischemia of the testis, commonly seen in complete testicular torsion. Grade 1 is characterized by the presence of 1-2 punctate vascular signa, indicating markedly reduced perfusion, which is more common in severe testicular damage or post-torsion recovery. Grade 2 indicates the presence of linear or multiple punctate vascular signals, suggesting moderate perfusion, which may be observed in some testicles with smaller volumes. Grade 3 represents abundant and evenly distributed microvascular flow, consistent with normal testicular perfusion [28, 29]. Our results demonstrated that, compared with the control group, patients in the case group had significantly lower SMI grades, particularly an increased proportion of grade 0 and grade 1. Furthermore, SMI demonstrated good diagnostic performance for semen abnormalities, with a sensitivity of 83.33% and specificity of 96.0%. When combined with SWE, the sensitivity incrased to 87.33% and specificity to 99.0%. In addition, SMI grading was significantly associated with semen quality, further supporting its potential role in the functional assessment of spermatogenesis.

This study has several limitations. First, it was a single-center retrospective study with a relatively limited sample size, which may affect the generalizability of the findings. Multicenter studies with larger cohorts are warranted in the future. Second, semen evaluation was limited to conventional parameters, and more detailed examinations such as sperm DNA fragments and sperm morphology abnormalities, were not included, which may provide additional diagnostic information.

Conclusion

SMI and SWE are advanced ultrasound techniques with unique advantages in the evaluation of testicular pathology. Both SMI and SWE are significantly associated with semen abnormalities. Moreover, their combined application further improves diagnostic performance.

Disclosure of conflict of interest

None.

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