JOURNAL OF
CONTEMPORARY MEDICINE

DOI:10.16899/jcm.1611569
J Contemp Med 2025;15(2):58-62

Original Article / Orijinal Araştırma

Comparison of Testicular Elasticity with Histogram Analysis of Testicular Echogenicity

Testis Elastikiyetinin Testis Ekojenitesinin Histogram Analizi ile Karşılaştırılması

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Abstract

Aim: This study aims to evaluate the relationship between testicular tissue elasticity and ultrasound (US) histogram analysis obtained from testicular echo signals. The goal is to explore whether quantitative texture analysis can complement traditional US findings.

Material and Method: 46 patients with 92 testis were examined using B-mode ultrasound and strain elastography (SE). A transverse US image was analyzed for each testis to extract histogram parameters such as mean, standard deviation, skewness, kurtosis, and entropy. SE was used to measure testicular elasticity.

Results: Histogram analysis showed a significant correlation between age and homogenization of testicular tissue ($r=0.444$; $p<0.001$). Strain ratios were positively correlated with the mean region of interest (ROI) signal value ($r=0.627$; $p<0.001$), whereas an inverse correlation was found between the mean entropy values and strain ratios ($r=-0.683$; $p<0.001$).

Conclusion: These findings suggest that higher echo entropy increases testicular elasticity. This quantitative analysis offers a new objective method for assessing testicular function and provides data complementary to traditional ultrasound techniques.

Keywords: Histogram analysis; Male infertility; Testis; Ultrasound elastography

Öz

Amaç: Bu çalışmanın amacı testis dokusu elastikiyeti ile testis eko sinyallerinden elde edilen ultrason (US) histogram analizi arasındaki ilişkiyi değerlendirmektir. Amaç, kantitatif doku analizinin geleneksel US bulgularını tamamlayıp tamamlayamayacağını araştırmaktır.

Gereç ve Yöntem: 92 testisi olan 46 hasta B-mod ultrason ve gerinim elastografisi (SE) kullanılarak incelendi. Her testis için ortalama, standart sapma, çarpıklık, basıklık ve entropi gibi histogram parametrelerini çıkarmak için transvers US görüntüsü analiz edildi. SE, testis elastikiyetini ölçmek için kullanıldı.

Bulgular: Histogram analizi yaş ile testis dokusunun homojenizasyonu arasında önemli bir korelasyon gösterdi ($r=0,444$; $p<0,001$). Gerinim oranları ortalama ilgi alanı (ROI) sinyal değeri ile pozitif korelasyon gösterdi ($r=0,627$; $p<0,001$), ortalama entropi değerleri ile gerinim oranları arasında ise ters bir korelasyon bulundu ($r=-0,683$; $p<0,001$).

Sonuç: Bu bulgular daha yüksek eko entropisinin testis elastikiyetini artırdığını göstermektedir. Bu kantitatif analiz, testis fonksiyonunu değerlendirmek için yeni bir objektif yöntem sunar ve geleneksel ultrason tekniklerine tamamlayıcı veriler sağlar.

Anahtar Kelimeler: Histogram analizi; Erkek infertilitesi; Testis; Ultrason elastografi

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Received *(Geliş Tarihi)*: 02.01.2025 **Accepted *(Kabul Tarihi)*:** 09.02.2025

INTRODUCTION

The primary causes of male infertility, which affect approximately 7.5% of couples of reproductive ages, include varicocele, undescended testis, hypogonadism, genetic abnormalities, previous genital surgeries, and urogenital infections.[1,2] Currently, diagnosing male infertility requires both physical examination and ultrasonographic (US) evaluation of the testis.[3] The US is the preferred imaging technique for detecting testicular abnormalities and assessing various conditions, such as swelling, scrotal pain, and infertility.[4,5] Traditionally, urologists and andrologists use tissue palpation to evaluate scrotal stiffness; however, this method is subjective and relies heavily on clinician experience.[5] Ultrasound elastography is an innovative technique that measures tissue stiffness by applying mild compression using an ultrasound transducer that causes tissue changes based on its elastic properties.[6] There are two primary types of elastography: strain elastography (SE) and shear- wave elastography (SWE).[1,5] SE measures relative tissue displacement in response to applied pressure, whereas SWE utilizes acoustic radiation force to generate shear waves, which travel through the tissue at a speed dependent on tissue stiffness. SE is advantageous for real-time qualitative and semi-quantitative evaluation, but it depends on operator technique and external compression, leading to variability. In contrast, SWE provides quantitative measurements and is less operator-dependent, but it is sensitive to motion artifacts and requires specialized software. SE has become an additional tool for identifying pathological tissue changes, and large-scale studies on testicular tissue have used SE techniques.[7-10]

Extraction of quantitative features from medical images has become increasingly prevalent in diagnostic imaging. Advanced image analysis methods enable complex pattern recognition, which can be used alongside subjective assessments to enhance quality evaluation, image optimization, and interpretation.[11] This process, known as radiomics, is a new engineering approach that overcomes the visual limitations of radiologists by extracting high-dimensional data from medical images as quantitative features.[11-13]

This study aimed to develop a quantitative method for extracting texture features from testicular ultrasound images, with a focus on assessing testicular elasticity. Traditional ultrasound evaluations often rely on subjective visual assessments, which can vary among the operators. To address this issue, we employed a radiomics approach that allows the extraction of high-dimensional data to provide objective and reproducible measurements. The goal of this study was to explore how texture analysis can complement existing ultrasound techniques by offering additional operator-independent information for predicting testicular stiffness.

MATERIAL AND METHOD

Patient Selection

This study involving human participants was conducted in accordance with ethical guidelines and the principles outlined in the Declaration of Helsinki. It was approved by the local ethics committee (file number: 2015/104). The male patients who visited our outpatient clinic for infertility underwent testicular ultrasonography and strain elastography. Exclusion criteria included a history of testicular surgery, undescended testis, testicular microlithiasis, significant heterogeneity in echotexture, or low testicular volume. Low testicular volume was defined as a testicular volume of less than 12 mL, which is commonly accepted as the lower limit of normal adult testicular size.[2] This threshold was determined based on previous studies linking testicular volume to spermatogenic function and reproductive potential.

Equipment and Scanning

Image processing and feature extraction

A single experienced radiologist performed all B-mode ultrasound and strain elastography procedures to minimize inter-observer variability. B-mode and semi-quantitative SE were performed with patients in the supine position using an Aplio 400 Platinum (Toshiba Medical Systems Corporation, Tochigi, Japan) device, equipped with a 5-14 MHz linear transducer. Initially, the testicular parenchyma was scanned, and data were collected from both testis, including the following information: testis volume, echotexture, vascularization, testicular nodule detection, presence and grade of microlithiasis, description of the epididymis and vas deferens, and presence or absence of varicocele and hydrocele. The parenchyma of each testis was visually inspected for US inhomogeneity. Representative images of testicular parenchyma were selected for texture analysis. Strain elastography was performed immediately after the B-mode ultrasonography. To minimize movement artifacts, patients were asked to hold their breath during stiffness measurements. The local strain was obtained by applying mild repetitive compression using a rhythmic compression-relaxation cycle with the freehand technique while the probe was in the scanning position.[14] The SE image was displayed as a translucent, color-coded, real-time overlay on the B-mode image. Compression was repeated until more than three SE images were obtained. The stiffness of tissues is represented on a color-coded map: soft tissues in red, hard tissues in blue, and moderately elastic tissues in green.[15] The first ROI was placed in the subcutaneous fat tissue and the second ROI was placed over the testis. Using these ROIs, the strain values of both the subcutaneous fatty tissues and testis in the same image were determined. The strain ratio was automatically calculated using a sonographic device, as shown in **Figure 1** and **2**.

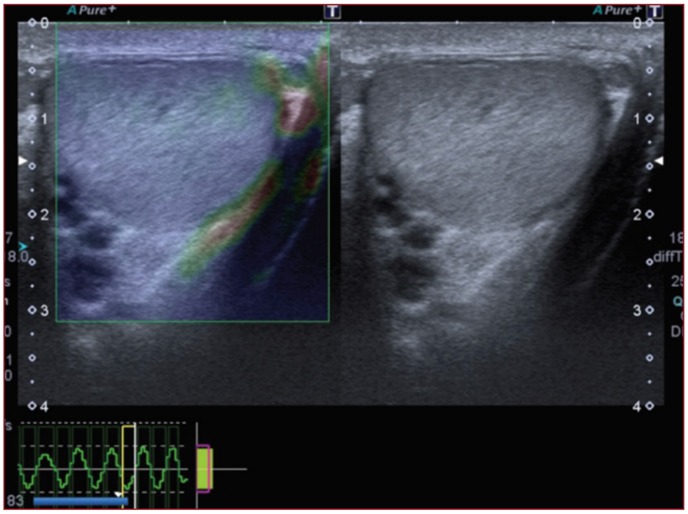

Figure 1. B mode and ultrasound elastography image of the left testis. Velocity profile during compression and decompression.

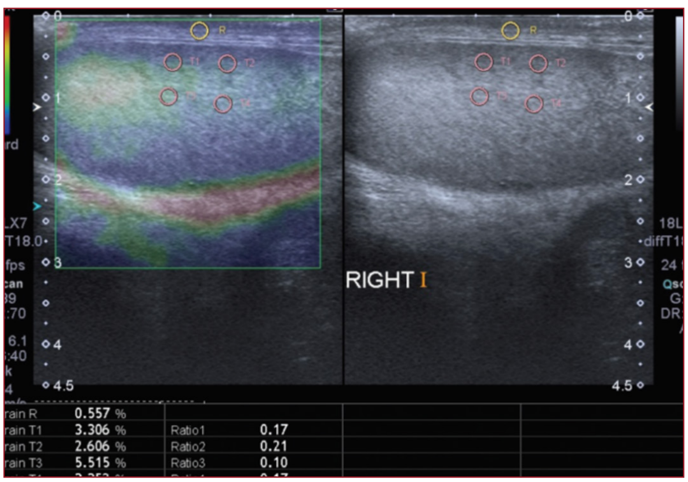

Figure 2. B mode and ultrasound elastography image of the right testis. The upper ROI is in the subcutaneous tissue and the lower four ROIs are in the subcapsular and intraparenchymal area.

Visual review and subsequent selection of saved DICOM images were performed. Each image was exported from the PACS server (2019, PacsOne Server version 6.8.1) in lossless image format [portable network graphics format (png)]. Radiomics was applied to ultrasound images in four steps: (i) image segmentation, (ii) image preprocessing, (iii) extraction of texture features, and (iv) statistical analysis. All image processing algorithms were created using MATLAB R2020b (MathWorks, Natick, Massachusetts, USA). These descriptors, known as textural features, can quantify the characteristics of the image texture. For the texture analysis, only pixel values within the segmented region were considered. Using this algorithm, we extracted texture features, including mean, standard deviation, skewness, kurtosis, and entropy. These features quantify pixel intensity variations within a region of interest (ROI). The mean refers to the average value of pixel intensity or echogenicity in the ultrasound images, ranging from 0 (black) to 255 (white). The standard deviation represents the variation in pixel intensity. Skewness indicates asymmetry of the mean distribution, whereas kurtosis measures the sharpness or flatness of the distribution peak. (Kurtosis is defined as a measure of the peakness of a distribution). Higher kurtosis values suggest a more peaked distribution, whereas lower kurtosis values indicate a flatter one. Entropy measures the randomness in the pixel distribution, with higher values indicating greater texture complexity.[16]

Statistical Analysis

Statistical analyses were performed using SPSS version 22. The mean values of the histogram parameters and strain ratios were compared between the tests using Student's t-test and Spearman's correlation analysis.

RESULTS

A total of 55 participants were considered eligible for the study. However, five declined to undergo the proposed examination, and measurements for four participants were unreliable because of motion artifacts. Consequently, 46 patients with 92 testis were included in the final analysis. The youngest participants were 20 years old, while the oldest were 55. The mean age of the patients was 36.73±12.43 years, ranging from 22 to 55 years. No parameters were found to cause differences between the testicles.

Based on the histogram analysis, as age increased, the regions representing one SD above and below the mean in the ROI echo signal decreased, whereas the middle region increased ($r=0.444$; $p<0.001$), indicating homogenization. The strain ratios showed an increase in correlation with the increase in the mean ROI signal value ($r=0.627$; $p<0.001$), as shown in **Figure 3**. A significant and strong inverse relationship was observed between the mean entropy values and strain ratios ($r=-0.683$; $p<0.001$), as shown in **Figure 4** and **Table 1**.

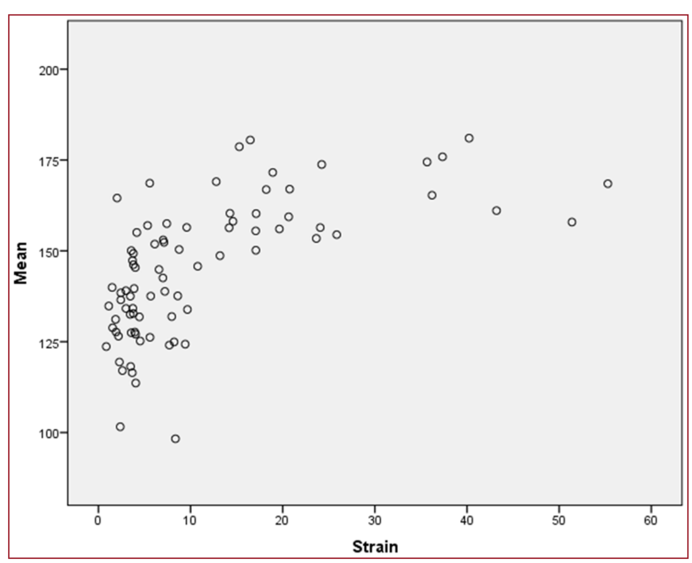

Figure 3: As the mean ROI signal value increased, strain rates also increased ($r=0.627$; $p=0.000$).

Table 1: Histogram analysis and strain ratio mean findings.

N (92)	Mean	Std. Deviation	Minimum	Maximum
Mean	141,44	21,53	87,15	181,03
Std. Deviation	16,52	2,75	11,04	24,85
Minimum	91,33	18,20	42,00	132,33
Maximum	190,76	19,64	134,67	229,00
Median	141,90	22,51	85,33	182,17
Variance	280,46	94,53	121,86	617,44
Size %L	16,72	1,53	12,93	21,93
Size %U	16,20	1,03	13,30	18,55
Size %M	67,09	2,08	60,51	71,62
Entropy	0,56	0,35	0,00	1,00
Strain Ratio	12,62	13,17	0,85	57,19

Size %U areas containing one SD above, Size %L below and Size %M between both.

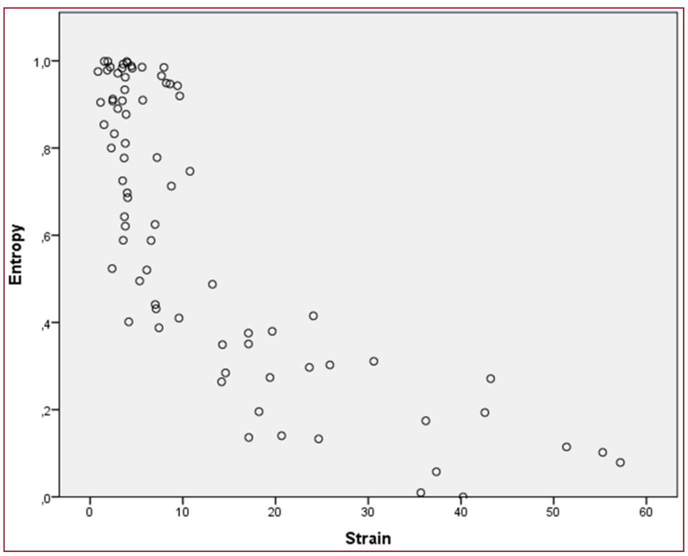

Figure 4: A histogram analysis revealed a significant and strong inverse relationship (r=-0.683; p=0.000) between the mean entropy values and strain rates.

DISCUSSION

This study confirmed that objective texture analysis of testicular ultrasound images correlates well with the visual features commonly used in subjective assessments, such as contrast, uniformity, and edge structures within the images. More importantly, our findings revealed that testicular tissue became more elastic as entropy increased, indicating that echo entropy could serve as a quantitative marker of tissue elasticity. This finding suggests that texture analysis has the potential to become a valuable quantitative tool for assessing testicular function. For texture analysis to hold diagnostic value, findings must closely align with the underlying pathophysiology. In other words, the appearance of testicles on imaging corresponds to their anatomy, functional state, or dysfunction. Studies have shown that testicular ultrasonographic texture can change in cases of impaired semen quality and carcinoma in situ.[13,17,18] Thus, it is plausible that in images of nodular lesions, textural features are modified because of disrupted spermatogenesis and the presence of nodular abnormalities.

Several studies have attempted to measure testicular stiffness, but most have focused on tumor cases, with few studies examining non-tumoral conditions such as infertility. For instance, Trottmann et al. conducted a study measuring testicular stiffness in healthy volunteers, but their sample had limitations, including the older age of participants (mean age 51.86 years) and the lack of fertility-related data.[1] In contrast, our study examined younger patients with infertility concerns, which more accurately reflects the clinical population in need of such assessment.

Most parameters collected in ultrasound-based testicular assessments tend to provide only a qualitative assessment of the male gonad, which is often influenced by both intra- and inter-operator variability and operator subjectivity. Normally functioning testis are characterized by a uniform echotexture with homogeneously distributed medium-level echoes.[10] Conversely, impaired testicular function is typically linked to ultrasound inhomogeneity, seen as regions of altered echogenicity, predominantly hypoechoic.[19]

One novel aspect of this study was the application of radiomics, which extends beyond traditional visual assessments. Radiomics enables the extraction of high-dimensional data and provides objective measurements of tissue characteristics that complement traditional sonographic evaluations. The use of radiomics has increased in recent years, with applications extending to oncological imaging and various other organ systems.[20] Radiomics has been validated in various contexts for its ability to describe tissue structures and predict the functions of the thyroid, breast, kidney, and prostate.[21-24] Additionally, outside of oncology, radiomics has shown potential in providing valuable and reliable imaging biomarkers for gonadal function.[12] In contrast, only a limited number of studies have assessed radiomics using testicular ultrasonography.[25] By combining radiomic data with standard ultrasound assessments, we can offer a more comprehensive evaluation of testicular tissue, potentially reducing operator dependency and improving the diagnostic accuracy. Future studies should focus on expanding the dataset used in machine-learning models, extracting a greater number of ultrasound texture features, and exploring deep learning algorithms for automatic and more complex feature extraction.

Although our results are promising, this study had several limitations. First, it was conducted with a relatively small sample size, which limits the generalizability of our findings. Larger multicenter studies are required to validate our results and to improve the robustness of the mathematical model used for texture analysis. Additionally, all ultrasound and elastography measurements were performed by a single operator, which means that we were unable to assess interobserver variability. Future studies should address this issue by incorporating multiple observers to ensure the reproducibility of the technique.

Another limitation was the lack of clinical integration of radiomics into testicular ultrasound. Although our study highlights the potential of radiomics in this field, it remains largely an experimental tool. For clinical adoption, further research is needed to standardize the texture features extracted from ultrasound images and establish clear diagnostic thresholds for testicular elasticity and other relevant parameters.

CONCLUSION

This study suggests that texture analysis of testicular ultrasound images offers a promising quantitative approach for assessing testicular elasticity, particularly in infertility evaluations. By refining elastography techniques and ensuring standardization, radiomics has the potential to provide objective, operator-independent data that could enhance diagnostic precision and improve clinical decision-making.

ETHICAL DECLARATIONS

Ethics Committee Approval: The study protocol was approved by the Kahramanmaraş Sütçü İmam University Medical Research Ethics Committee (Decision No: 2015/104).

Informed Consent: Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Financial Disclosure: No research funding was received for this study.

Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

REFERENCES

1. Trottmann M, Marcon J, D'Anastasi M, et al. Shear-wave elastography of the testis in the healthy man- determination of standard values. Clin Hemorheol Microcirc 2016;62(3):273-81.
2. Nieschlag E, Behre HM. Approaches to hormonal male contraception. In: Nieschlag E, Behre HM, Nieschlag S, editors. Andrology: male reproductive health and dysfunction, 3rd edn. Springer, Heidelber; 2010;577–87.
3. Lotti F, Maggi M. Ultrasound of the male genital tract in relation to male reproductive health. Hum Reprod Update 2015;21(1):56-83.
4. Bernardo S, Konstantatou E, Huang DY, et al. Multiparametric sonographic imaging of a capillary hemangioma of the testis: appearances on grayscale, color Doppler, contrast-enhanced ultrasound and strain elastography. J Ultrasound 2015;19(1):35-9.
5. Rocher L, Criton A, Gennisson JL, et al. Testicular Shear Wave Elastography in Normal and Infertile Men: A Prospective Study on 601 Patients. Ultrasound Med Biol 2017;43(4):782-9.
6. Oglat AA, Abukhalil T. Ultrasound Elastography: Methods, Clinical Applications, and Limitations: A Review Article. Appl Sci 2024;14(10):4308.
7. Schurich M, Aigner F, Frauscher F, Pallwein L. The role of ultrasound in assessment of male fertility. Eur J Obstet Gynecol Reprod Biol 2009;144 Suppl 1: S192-8.
8. Sarvazyan A, Hall TJ, Urban MW, Fatemi M, Aglyamov SR, Garra BS. An overview of elastography-an emerging branch of medical imaging. Curr Med Imaging Rev 2011;7(4):255-82.
9. Goddi A, Sacchi A, Magistretti G, Almolla J, Salvadore M. Real-time tissue elastography for testicular lesion assessment. Eur Radiol 2012;22(4):721-30.
10. Lai DK, Cheng ES, Mao YJ, et al. Sonoelastography for testicular tumor identification: a systematic review and meta-analysis of diagnostic test accuracy. Cancers (Basel) 2023;15(15):3770.
11. Gillies RJ, Kinahan PE, Hricak H. Radiomics: Images Are More than Pictures, They Are Data. Radiology 2016;278(2):563-77.
12. Fanni SC, Febi M, Colligiani L, et al. A first look into radiomics application in testicular imaging: A systematic review. Front Radiol 2023; 3:1141499.
13. De Santi B, Spaggiari G, Granata AR, et al. From subjective to objective: A pilot study on testicular radiomics analysis as a measure of gonadal function. Andrology 2022;10(3):505-17.
14. Cui XW, Li KN, Yi AJ, et al. Ultrasound elastography. Endosc Ultrasound 2022;11(4):252-74.
15. Urhuț MC, Săndulescu LD, Ciocâlteu A, Cazacu SM, Dănoiu S. The clinical value of multimodal ultrasound for the differential diagnosis of hepatocellular carcinoma from other liver tumors in relation to histopathology. Diagnostics (Basel) 2023;13(20):3288.
16. DeJohn CR, Grant SR, Seshadri M. Application of machine learning methods to improve the performance of ultrasound in head and neck oncology: a literature review. Cancers (Basel) 2022;14(3):665.
17. Lotti F, Studniarek M, Balasa C, et al. The role of the radiologist in the evaluation of male infertility: recommendations of the European Society of Urogenital Radiology-Scrotal and Penile Imaging Working Group (ESUR-SPIWG) for scrotal imaging. Eur Radiol. 2025;35(2):752-66.
18. Spaggiari G, M Granata AR, Santi D. Testicular ultrasound inhomogeneity is an informative parameter for fertility evaluation. Asian J Androl 2020;22(3):302-8.
19. Lotti F, Frizza F, Balercia G, et al. The European Academy of Andrology (EAA) ultrasound study on healthy, fertile men: An overview on male genital tract ultrasound reference ranges. Andrology 2022;10(2):118-32.
20. Pietsch FL, Haag F, Ayx I, et al. Textural heterogeneity of liver lesions in CT imaging-comparison of colorectal and pancreatic metastases. Abdom Radiol (NY) 2024;49(12):4295-306.
21. Yoon J, Lee E, Kang SW, Han K, Park VY, Kwak JY. Implications of US radiomics signature for predicting malignancy in thyroid nodules with indeterminate cytology. Eur Radiol 2021;31(7):5059-67.
22. Satoh Y, Hirata K, Tamada D, Funayama S, Onishi H. Texture analysis in the diagnosis of primary breast cancer: comparison of high-resolution dedicated breast positron emission tomography (dbPET) and Whole-Body PET/CT. Front Med (Lausanne) 2020;7:603303.
23. Abbasian Ardakani A, Sattar AR, Abolghasemi J, Mohammadi A. Correlation between kidney function and sonographic texture features after allograft transplantation with corresponding to serum creatinine: a long-term follow-up study. J Biomed Phys Eng 2020;10(6):713-26.
24. Huang X, Chen M, Liu P, Du Y. Texture feature-based classification on transrectal ultrasound image for prostatic cancer detection. Comput Math Methods Med 2020;(6);2020: 7359375.
25. Ghayda RA, Cannarella R, Calogero AE, et al. Artificial intelligence in andrology: from semen analysis to image diagnostics. World J Mens Health 2024;42(1):39-61.