DOI: https://doi.org/10.18621/eurj.1401693 *Radiology*

Comparison of testicular stiffness values obtained by ultrasound shear-wave elastography and magnetic resonance elastography in normal healthy volunteers

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ABSTRACT

Objectives: This study aimed to contribute to the standardization of elastography by comparing stiffness values obtained from ultrasound shear wave elastography (SWE) and magnetic resonance elastography (MRE) of the testicular parenchyma in healthy volunteers.

Methods: A total of 22 healthy volunteers (44 testes) were included in this study. Of the 26 cases analyzed, four were excluded from the study due to the exclusion criteria. The testicular parenchyma of the included patients was evaluated using MRE and SWE examinations. Pearson's correlation test was used to calculate the correlation between age and stiffness values, testicular volumes and stiffness values, and stiffness values from both examinations.

Results: The mean SWE stiffness of the right testes was 5.560±3.1 kPa and the mean SWE stiffness of the left testes was 5.361±2.9 kPa. The mean MRE stiffness of the right testes was 6960.11±460 Pa and the mean MRE stiffness of the left testes was 6560.19±310 Pa. There was no significant correlation between SWE and MRE stiffness values (P=0.096). There was also no significant statistical correlation between SWE and MRE stiffness values and testicular volumes (P=0.17 and P=0.093, respectively).

Conclusion: No statistical correlation was found between the stiffness values obtained by SWE and those obtained by MRE in the normal testicular parenchyma. Additionally, no conclusive relationship between stiffness levels, age, or testicular volume was discovered.

Keywords: Elastography, magnetic resonance imaging, stiffness, testis, ultrasonography

Ultrasonography (USG) is the most sensitive and specific examination method for the testes. However, it is limited to evaluating the surrounding vascular structures and arteries supplying the testicular parenchyma with Doppler, roughly observing the intraparenchymal structures on a greyscale, and providing objective data on the testicular parenchyma only for easily visible peripheral and intraparenchymal mass lesions and apparent vascular abnormalities [1, 2].

Although normal radiological findings are detected on greyscale USG and color Doppler examination of the testicular parenchyma in a small number of patients presenting with infertility, obvious abnormal-

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How to cite this article: Poçan S, Karakaş L. Comparison of testicular stiffness values obtained by ultrasound shear-wave elastography and magnetic resonance elastography in normal healthy volunteers. Eur Res J. 2024;10(2):178-186. doi: 10.18621/eurj.1401693

Received: December 7, 2023
Accepted: January 4, 2024
Published Online: February 8, 2024

ities in the testicular parenchyma, its size and volume, and pathological conditions other than varicocele are uncommon radiological findings in infertility [1].

It is not possible to detect more micro-level abnormalities in the testicular parenchyma on greyscale USG examination, except for space-occupying lesions in the parenchyma or point calcifications, known as microlithiasis and inflammatory processes. However, varicocele, atrophy, and parenchymal grayscale abnormalities have not been detected in many patients with infertility. As the testis is not a suitable organ for biopsy, hardness remains a measurable parenchyma parameter [2].

Elastography is a sonographic imaging technique that provides qualitative and/or quantitative information regarding tissue stiffness. It is based on the degree of deformation of the analyzed lesion compared with the surrounding tissue. Images are obtained in color tones from red to blue, or vice versa, and from soft to hard, depending on the tissue stiffness. This color map provides both relative and qualitative data. Shear wave elastography (SWE) is a newly developed real-time sonographic imaging technique that provides quantitative information (in N/m2 or kPa) on the elasticity of soft tissues by sending transverse waves to the examined tissue [2].

Elastography is considered the gold standard radiological method for testicular imaging and has been used as an additional diagnostic examination in recent years because it offers additional parameters while remaining faithful to the basic principles of ultrasonography. However, the procedure is operator dependent and a wide range of unstandardized data has been presented in the literature. Therefore, the idea of standardizing this examination by comparing it with magnetic resonance elastography (MRE), which works with a similar logic but with different physical laws, has emerged. These comparison and standardization studies have been carried out extensively on liver imaging, in which elastography is extensively used.

METHODS

Ethical Issues, Settings, and Study Design

Our study was conducted at the Radiology Department of BHT Clinic Istanbul Tema Hospital, with the approval and permission of the Academic Board and

Fig. 1. **Touch panel and button panel of GE Logic S8 brand/model USG device with elastography software (elastography button is circled in red on the right) and a 9 Mhz linear probe with hardware elastography features (shown from two different directions on the left).**

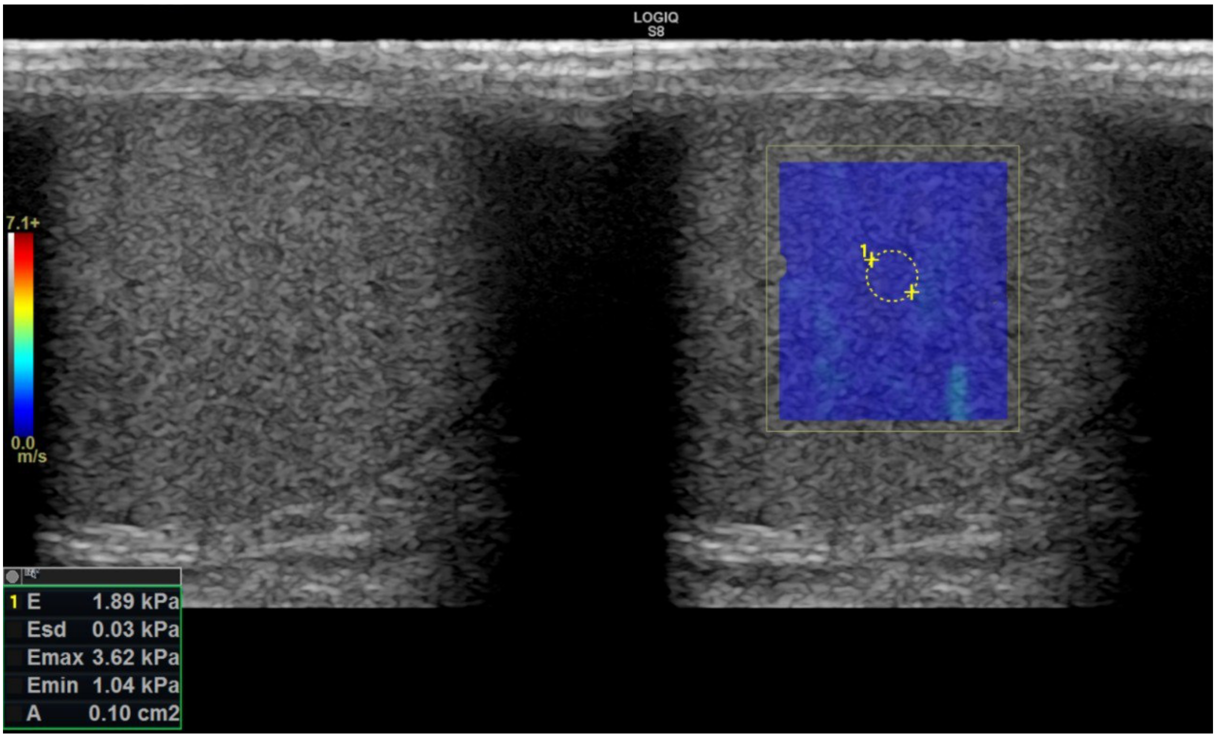

Fig. 2. SWE: Elastography image in the right window and simultaneous greyscale image in the left window. In the image on the right, a 0.1 cm2 ROI area (area surrounded by yellow dots numbered 1) was measured from the central part of the testis within the colored blue elastogram window. In the lower-left corner of the image, there are measurement values in units of kPa.

Ethics Committee of Istanbul Nişantaşı University (Date: 14.08.2023, No: 2023/33-12).

A total of 26 healthy volunteers were examined using SWE and MRE with permission from the university and hospital between August and November 2023. Our exclusion criterion was the presence of a herniated scrotal and/or epididymal abnormality on USG and/or magnetic resonance imaging (MRI). Four cases were excluded from the study due to microlithiasis in the testis, cysts in the epididymis, incidental and asymptomatic small testicular size (atrophy or hypoplasia), and hydrocele. Thus, 22 cases (44 testes) were evaluated in the present study. The obtained data were comparatively evaluated. SWE and MRE examinations were evaluated by two radiologists with more than 10 years of experience in scrotal USG and MRI and more than 2 years of experience in elastography.

Fig. 3. The apparatus called "passive driver," which is one of the extra equipment for MRE examination, is shown from the back, front, and side in three images from left to right.

Fig. 4. **The so-called "active driver", which is an additional component of the MRE examination, is shown.**

USG SWE Device, Technique, Assessment, Data Collection and Outcomes

The study was conducted using a General Electric (GE) brand Logic S8 model (2019) USG device with elastography software, utilizing a 9 MHz linear probe with elastography hardware (Fig. 1).

Ultrasonographic examination was performed with the patient in the supine position and the penis was positioned on the abdomen with a blanket covering it, ensuring that it was removed from the examination area.

Light pressure was applied to measure the three dimensions of each testis while in the supine posture. Testicular volume was estimated by the USG machine using the following method, based on comparable earlier investigations: Volume of testis = width × length × height × 0.523, expressed in milliliters (mL) [3, 4].

After completing the greyscale USG test, the radiologist initiated the SWE examination. Two-dimensional SWE was performed with the patient in a supine resting state. The probe was held as steady as possible during the SWE evaluation to minimize artifacts and inaccurate measurements. The right window displays the elastography image, whereas the left window displays the simultaneous grayscale image (Fig. 2). Elastographic examinations were conducted with minimal compression for at least 5 seconds to reduce motion artifacts. ROIs (regions of interest) were placed to measure a round area of 0.1 cm2 in the central part of the normal testicular parenchyma, as it is known that measurements become more standardized in this region, and the area becomes smaller in SWE [4, 5].

The ROI area (0.1 cm2 was our study's most optimum measurable standard (Fig. 2). Quantitative data mean (Emean) was obtained in kPa from the normal testicular parenchyma. In our study, the SWE images saved in our PACS archive and the measurements made during the procedure were retrospectively reviewed. The measured values were obtained in kPa units in the SWE. However, to compare them statistically with the values in Pa units in MRE, they were multiplied by 1000 to obtain the Pa value equivalents.

Real-time SWE measurements were performed during the examination and evaluated by transferring the data to the closed-circuit Clear Canvas Picture Archiving and Communication Systems (PACS) mod-

Fig. 5. In the leftmost picture, the passive driver device shown in Figure 2 is observed in the suprapubic region. In the central picture, it is fixed with a coil, and in the rightmost picture, it is observed with a coil placed on it.

ule in our hospital. Data from both examinations were collected and documented.

MRI and MRE Protocols Assessment, Data Collection, and Outcomes

All MRE examinations were conducted on a 3 Tesla General Electric Signa Architect MRI scanner with commercially available software and hardware (GE Healthcare, Waukesha, WI, and Resoundant Inc., Rochester, MN) [6, 7].

Technically, there are two non-standard extra hardware apparatuses in the MR device: a special device called a "passive driver" (Fig. 3) and another device called an "active driver" (Fig. 4) for elastography [7].

The subjects were positioned supine, head first, with a body AIR coil centered at the level of the region of interest [6]. Mechanical shear waves at 60 Hz were generated by using an active driver system outside the

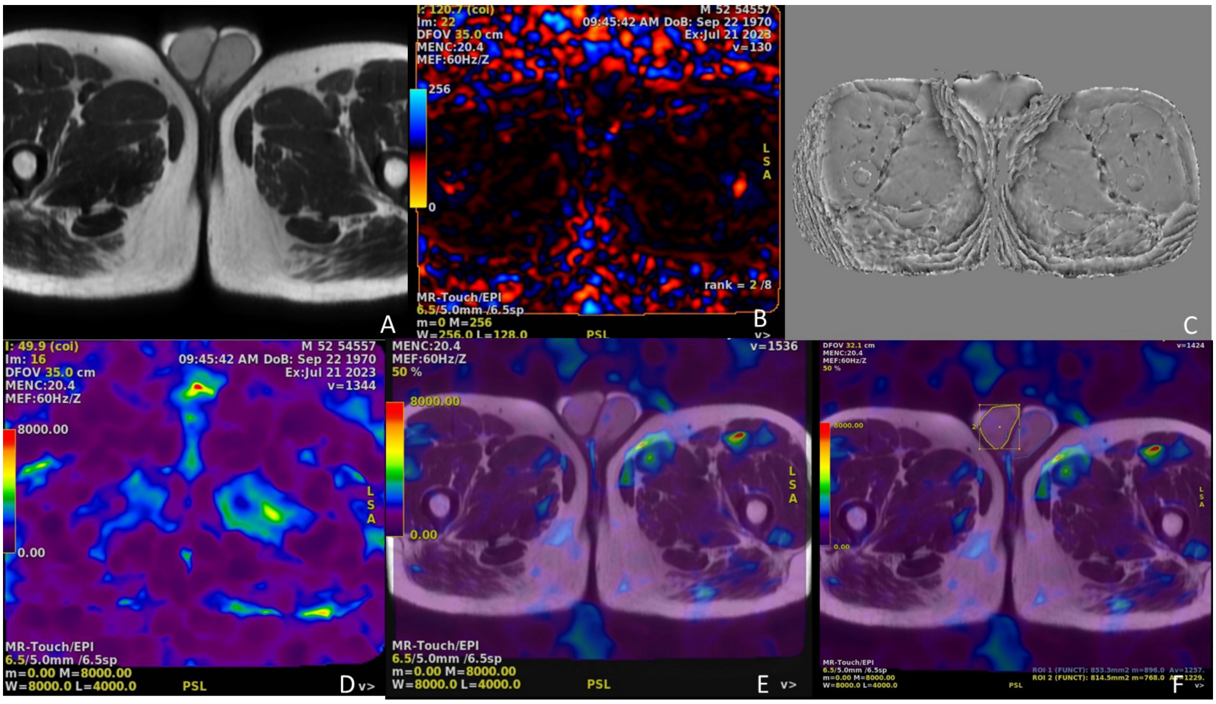

Fig. 6. In the top row, the leftmost image (A) is the axial spin-echo T2 sequence image, the middle image (B) is the elastography dynamic pressure color map, and the rightmost image (C) is the wave image. The leftmost image (D) is the stiffness color map and the middle image (E) is the elastography fusion image. In the rightmost image (F), the right testicular parenchyma was surrounded by a yellow line border and the left testicular parenchyma was surrounded by a blue line border, and measurements were made in Pa units from all of these areas of both testicular parenchymas over the fusion image.

MRI room. A rigid passive driver secured against the anterior wall of the pelvis was used to transmit mechanical vibrations from the active transducer to the body (Fig. 5). A rigid driver is the standard device used in the FDA-cleared commercially available implementation of MRE technology. An experienced MRI technologist performed the MRE examinations in this study.

The propagating shear waves were imaged using a motion-sensitized imaging sequence. A (Spin-Echo echo planar imaging (SE-EPI) sequence was used to acquire axial wave images with the following parameters: repetition time (ms)/echo time (ms), 50/23; continuous sinusoidal vibration, 60 Hz; field of view, 32-42 cm; matrix size, 256 × 64; flip angle, 30°; section thickness, 10 mm; four evenly spaced phase offsets; and four pairs of 60-Hz trapezoidal motion-encoding gradients with zeroth and first moment nulling along the through-plane direction. All processing steps were applied automatically, without manual intervention, to yield quantitative images of tissue shear stiffness in kilopascals. The MR elastographic images were interpreted by staff radiologists in the Department of Radiology.

MRE images were processed using commercially available MR-Touch software (GE Healthcare, Waukesha, WI, and Resoundant Inc., Rochester, MN, USA) to generate magnitude, phase, and wave maps (Fig. 6) [6, 7]. Six relative stiffness images were reconstructed for each slice location. The resulting data were measured using ROIs in the muscle on anatomical T1 images and copied onto MRE stiffness maps to measure the stiffness values (or elastograms) in the Pascals.

Statistical Analysis

The MRE and SWE mean stiffness values were statistically analyzed in the Pascals. The SWE and MRE data were compared using the analysis of variance test, and chi-square and binary comparisons were performed using Student's t-test. Pearson's correlation test was used to calculate the correlation between age and stiffness values, testicular volumes and stiffness values, and stiffness values from both examinations. Statistical analysis was performed using SPSS v.23.0 (IBM Corp., Armonk, NY, USA). Two-tailed values of $P<0.05$ were considered statistically significant.

RESULTS

The youngest patient was 23 years old, and the oldest patient was 48 years old, with a mean age of 36.2±11 years). When analyzing the right testicular volumes of our patients, the largest value was 15 mL, and the smallest value was 12 ml. The mean right testicular volume was 13.4±3.1 ml. When analyzing the volumes of the left testes, the largest volume was 15.2 ml, and the smallest was 11 mL. The mean left testicular volume was 13.6 ± 3.2 mL (Table 1). No significant correlation was observed between age and testicular volume (Table 2).

When analyzing US-E stiffness values, the smallest stiffness value for the right testis, was 4.216 kPa, the highest stiffness value was 7.312 kPa, and the mean stiffness value was 5.560±3.1 kPa. For the left testis, the smallest and highest stiffness values were 4.324 kPa, 6.914 kPa, and 5.361±2.9 kPa (Table 3).

Because MRE stiffness values were given by the MR device in Pascal (Pa) units, data were collected in this unit. When analyzing the MRE values, it was observed that the smallest stiffness value for the right testis was 5302.12 Pa, the highest stiffness value was 9211 Pa, and the mean stiffness value was 6960±460 Pa. For the left testis, the smallest stiffness value was 5562 Pa, the highest stiffness value was 8913 Pa, and the average stiffness value was 6560±310 Pa (Table 4).

In the statistical correlation analysis performed between the testicular volume obtained from USG and the SWE stiffness values and the stiffness values measured by MRE ($P=0.17$ and $P=0.093$, respectively), and were found to be greater than 0.05, respectively (Table 5). This indicates that there were no statistically significant differences between the parameters.

When statistically correlating the SWE and MRE

Table 1. Smallest, largest and mean volumes of both testes volume (mL)

	Right	Left
Min.	12	11
Max.	15	15.2
Mean±SD	13.4±3.1	13.6±3.2

Max.=maximum, Min.=:minimum, SD=standart deviation, mL= milliliter

Table 2. Table showing the relationship between testicular volume and age

Age (years)	Right testis volume (mL)	Left testis volume (mL)
36.2±11	13.4±3.1	13.6±3.2
	P=0.083	P=0.27

Data are shown as mean±standard deviation. P value (Pearson's correlation coefficient), mL= milliliter

Table 3. SWE stiffness values (kPa)

	Right	Left
Min.	4.216	4.324
Max.	7.312	6.914
Mean±SD	5.560±3.1	5.361±2.9

SWE=shear wave elastography, kPa=kilopascal, Max.=maximum, Min.=:minimum, SD=standart deviation

Table 4. MRE stiffness values (Pa)

	Right	Left
Min.	5302.12	5562.23
Max.	9211.10	8913.22
Mean±SD	6960.11±460	6560.19±310

MRE=magnetic resonance elastography, Pa=pascal, Max.=maximum, Min.=:minimum, SD=standart deviation

Table 5. Binary comparison between USG volume versus US-E stiffness and MRE stiffness

USG volume (mL)	SWE stiffness (kPa)	MRE stiffness (Pa)
	P=0.17	P=0.093

USG=ultrasonography, SWE=shear wave elastography, MRE=magnetic resonance elastography, kPa=kilopascal, Pa=pascal. P value (Pearson's correlation coefficient)

Table 6. Binary comparison of each mean SWE stiffness and MRE stiffness values four each testis

Device	Mean stiffness value	P value
SWE	5.431 kPa	0.096
MRE	6763.44 Pa	

SWE=shear wave elastography, MRE=magnetic resonance elastography, kPa=kilopascal, Pa=pascal
P value (Pearson's correlation coefficient)

stiffness values of the cases, no significant correlation was found between the values (Table 6).

DISCUSSION

Numerous studies have been conducted on different normal distributions of testicular volume for different age groups [7-9]. When analyzing the testicular volumes of our patients, we observed that they were within the normal range for adults. This is because we included subjects from the normal population in the study. All of our patients were in the young and early middle age groups. When comparing age and testicular volume, no significant statistical correlation was found, which is consistent with most other data in the literature [9-13].

SWE is a relatively novel, reliable, and non-invasive imaging technique that provides data on histopathological alterations in many tissues. It offers a valuable quantitative assessment of tissue stiffness and is extremely helpful in assessing parenchymal diseases. SWE has been used in very few comparative investigations of the impact of varicocele on testicular parenchyma [14, 15].

When analyzing the SWE stiffness values, it was observed that they were similar to those in the literature. Most studies in the literature, especially in adults, aim to identify conditions that do not cause significant abnormalities in the testicular parenchyma on grayscale USG examination, especially varicocele. Although our number of cases and, therefore, our sample size was small, our similar stiffness value findings with the literature revealed that most pathologies that do not give significant findings in the testicular parenchyma on greyscale USG do not give significant findings on SWE.

No significant difference was found in the statistical analysis of the volume obtained by ultrasonographic calculation by measuring three dimensions compared to SWE and MRE. This result is consistent with data in the literature [13].

The MRI device provided the MRE stiffness values in the pascals. Currently, MRE is mostly used for the liver, and researchers who use this examination also use the Pascal unit. The MRE devices and software were calibrated to provide stiffness values in the Pascals.

The use of MRI of the testis in the literature is mostly to create a multiparametric examination for recognizing malignant lesions [16]. Although the use of US-E for testes is considerable in the literature, the same is not the case for MRE. We did not find any MRE studies of the testes in the literature. The MRE component of our study is a preliminary study. This may be criticized because it may produce meaningless results for statistical sampling and power analysis. However, since MRE is a test whose standards are not fully established, except for liver fibrosis, only pioneering studies can contribute to the literature. Similarly, there is only one study in the literature on the spleen, consisting of 16 patients [17].

I n the statistical comparative analysis of the data obtained for each testicle, there was no significant correlation between SWE and MRE findings (P=0.096). This nonsignificant correlation may be due to several factors and limitations. One of the most important of these factors is that the current MRE modality is not standardized enough to perform testicular examination.

Limitations

The lack of data on the MRE examination of the testes in the literature constitutes our most significant limitation. Another limitation is the small number of patients. Another limitation is that we performed MRE measurements from the whole parenchyma and SWE measurements from a single location.

CONCLUSION

In our study, we compared the MRE and SWE stiffness values of normal testicular parenchyma but did not find a statistically significant correlation between the two values. In addition, no significant correlation was found between stiffness values and age and testicular volume. The lack of a significant correlation may be attributed to the limitations and absence of standardized application standards for MRE in testicular examinations. Further research with more patients under more standardized conditions is needed to confirm this result. Despite the small number of patients, our study is significant, as it pioneers the literature on this subject.

Authors' Contribution

Study Conception: SP, LK; Study Design: SP, LK; Supervision: SP, LK; Funding: SP, LK; Materials: SP, LK; Data Collection and/or Processing: SP, LK; Statistical Analysis and/or Data Interpretation: SP, LK; Literature Review: SP, LK; Manuscript Preparation: SP, LK and Critical Review: SP, LK.

Conflict of interest

The authors disclosed no conflict of interest during the preparation or publication of this manuscript.

Financing

The authors disclosed that they did not receive any grant during the conduction or writing of this study.

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