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Role of Strain Elastography in the Evaluation of Testicular Torsion

An Experimental Study

Duygu Herek, MD, Ozkan Herek, MD, Metin Akbulut, MD, Furkan Ufuk, MD

Objectives—To evaluate the utility of real-time strain elastography in experimentally induced testicular torsion at different degrees and torsion hours.

Methods—Thirty-one Wistar albino rats were divided into 4 torsion groups by twisting left testes (group I, sham operated; group II, 360°; group III, 720°; and group IV, 1080°). Elastography was applied at the 8th and 24th hours of torsion. Elasticity patterns (pattern 1, soft testis; pattern 2, moderately soft testis; pattern 3, predominantly hard testis; and pattern 4, almost entirely hard testis) and strain ratios were recorded. Histopathologic evaluation was done at the 24th hour. Interobserver agreement was analyzed.

Results—Changes in elastographic patterns and strain ratios among groups II, III, and IV were statistically significant at both hours as determined by both radiologists ($P < .01$). Elastographic patterns changed from 2 to 3 in groups II and III to 4 in group III between the 8th and 24th hours ($P < .05$), but in group IV, patterns were reversed, and pattern 1 was observed at both hours. Pathologically severe necrosis (grade 4) was seen in left testes in group IV. In the other groups, pathologic grading in the left testes was as follows: mostly grade 1 in groups I and II and mostly grade 2 in group III. Elastography showed that right testes were affected in group IV, with significant differences in elastographic patterns and strain ratios ($P < .01$). Interobserver agreement for elastographic patterns in right testes was substantial at the 8th hour ($\kappa = 0.72$) and otherwise excellent ($\kappa = 0.81$–0.85). Concordance of strain ratios between observers was excellent for right and left testes at the 8th and 24th hours (intraclass correlation coefficients, 0.990 at the 8th hour and 0.987 at the 24th hour).

Conclusions—Our results show that real-time strain elastography can be a complementary method in the evaluation of testicular tissue in testicular torsion and can guide surgeons in their surgical approach.

Key Words—experimental animal models; genitourinary ultrasound; laboratory; rats; strain elastography; testicular torsion; testis

Testicular torsion is an important cause of acute scrotum, which occurs by twisting of the spermatic cord around itself and results in either decreased or absent perfusion of the testicle. It is commonly seen in adolescent boys, and its incidence is reported to be 1 per 4000 men by 25 years.[1–3] It is an ischemic injury to the testes, and subfertility, infertility, and hormonal irregularity are the impacts of this trauma.[4] Rapid diagnosis is critical for salvage of the testicle. The salvage rate is almost 100% if testicular blood flow is reestablished within 6 hours.[2–5] However, it decreases to 70% between 6 and 12 hours and to less than 10% after 24 hours.[3,4] The degree of

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Abbreviations
MRI, magnetic resonance imaging

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the spermatic cord twisting and duration of torsion are both important because both cause testicular necrosis when increased. For these reasons, prompt diagnosis is very important for salvage of the testicle.

Elastography is an ultrasound-based imaging technique that provides images related to the mechanical properties of tissues (stiffness and elasticity). Real-time strain elastography measures the response of a tissue to a force applied by the examiner, whereas shear wave elastography uses an acoustic push pulse, which measures the intrinsic tissue elasticity. In this study, we applied real-time strain elastography to experimentally induced testicular torsion models of different degrees (360°, 720°, and 1080°) at the 8th and 24th hours of torsion in the same rats and evaluated the efficacy and utility of real-time strain elastography in testicular torsion as a decision making technique for the salvageability of the testis. We wanted to establish elastographic differences that may exist between different torsion degrees at the 8th and 24th hours of torsion. Apart from the torsion degree, the possibility of reestablishment of blood flow is reported to be high during the first 6 hours of testicular torsion. However, it has been reported that most cases attending hospitals are after this period; therefore, deciding about salvageability of the testis becomes difficult.[2] These reasons affected our choice of time points, both of which were greater than 6 hours after the torsion procedure. We wanted to establish the role of real-time strain elastography for diagnosis and salvageability of the testis with delayed hospital attendance. To the best of our knowledge, real-time strain elastography at different degrees of testicular torsion and different durations in an experimental rat model has not been investigated previously.

Materials and Methods

Ethical Issues

This study was performed in accordance with the recommendations in the guidelines established by the *Guide for the Care and Use of Laboratory Animals* from the US National Institutes of Health (Bethesda, MD) and was approved by the local Institutional Ethics Committee on Animal Research. Experiments were conducted in the Animal Research Laboratory; elastography was done in the Department of Radiology; and histopathologic examinations were done in the Department of Pathology.

Animals

Thirty-one male albino Wistar rats, 10 to 12 weeks old and weighing 250 to 300 g, were used in this experimental study. The rats were housed in wire mesh cages in a cross-ventilated room (temperature of 22°C ± 2.0°C, with a 12-hour light/dark cycle) and had free access to standard rat chow and tap water.

Animal Model and Study Design

Experimental Design

Rats were divided randomly into 4 groups: a sham-operated group labeled as group I (n = 7) and 3 experimental groups labeled groups II, III, and IV (n = 8 per group). Surgical procedures and radiologic examinations were performed under ketamine/xylazine anesthesia and sterile conditions. Intramuscular injections of 50-mg/kg ketamine (Ketalar; Pfizer Pharma GmbH, Berlin, Germany) and 10-mg/kg xylazine HCl (Alfazyne; Alfasan International, Woerden, the Netherlands) were applied. Half of the given doses were repeated if needed. The control group was assigned as group I, which included the rats who had sham operations. Groups II, III, and IV underwent 360°, 720°, and 1080° of torsion of the left testes, respectively.

After ketamine/xylazine anesthesia, a 3-cm vertical incision was made on the left scrotum to gain access to the left testes. In group I, left testes with their vascular bundle were taken out of the scrotum for 1 minute and then replaced. Testicular torsion was induced by twisting left testes in clockwise direction. All left testes in the torsion groups were fixed from their upper and lower poles to the scrotal wall with 4/0 silk sutures to prevent detorsion. Scrotal incisions were closed with 4/0 silk sutures. After elastographic examinations at the 8th and 24th hours of torsion, rats underwent bilateral inguinal radical orchiectomy procedures. Orchiectomy materials were preserved in 10% formaldehyde solution and taken to the pathology laboratory.

Equipment and Scanning

The rats were brought to the Department of Radiology in cages, and anesthesia was applied just before the examinations. They were placed on a wooden tablet with 4 legs securely fixed to the tablet by plaster. Examinations were performed by 2 radiologists: radiologist 1 had 15 years of experience in conventional sonography and 2 years of experience in real-time strain elastography; radiologist 2 had 6 years of experience in conventional sonography and 2 years of experience in real-time strain elastography. First, color Doppler sonography was performed, and blood flow of bilateral testes was evaluated by radiologist 1. Then the scanner was switched to the elastographic mode. The radiologists did the measurements separately one after other for each rat. Static images were recorded at both hours and stored in the local ultrasound device for review after completion of the whole study. The radiologists evaluated the real-time strain elastograms that they had stored previously and were blinded to each other's measurements.

The examinations were performed with a LOGIQ E9 ultrasound scanner (GE Healthcare, Milwaukee, WI) equipped with an elastography-compatible 11–15-MHz linear transducer. The transducer was placed on the scrotum of the rats, with the scanning area including both the right and left testes. Local strain was achieved by slight compressions and decompressions by a freehand technique.[6,7] Maintenance of the applied force was controlled by a quality feedback bar, which indicated the quality of compression on a scale between 1 and 7. At least 5 bars of the indicator should have been active for optimal compression. The stiffness of the tissues was displayed in a color-coded map, where soft tissues appeared in red, hard tissues in blue, and intermediate degrees of elasticity in green.[8] The elastograms were obtained by overlaying color images on B-mode images. Ellipsoid regions of interest were placed over the testes, including the whole testis area.

Radiologic Evaluation

We classified the real-time strain elastograms into 4 patterns according to the tissue hardness by using a method developed by different authors, which has been explained in various studies (Figure 1).[8–12] Figures 2–4 give examples of cases with different elastographic patterns.

The elastographic pattern, as a qualitative variable, was noted for all right and left testes at the 8th and 24th hours of torsion. Elastographic patterns of the left and right testes of all groups were compared with each other (groups II, III, and IV compared with group I, groups III and IV compared with group II, and groups III and IV compared with each other) at the 8th and 24th hours of torsion separately. Automatically calculated strain ratios were also noted separately for both hours of torsion. The right testes were considered the reference areas and the twisted left testes the target areas. The strain ratio, which was automatically derived by the scanner, was achieved by placing the first region of interest on the right testes and the second region of interest on the left testes. All strain ratios in the groups were compared with each other (groups II, III, and IV compared with group I, groups III and IV compared with group II, and groups III and IV compared with each other) separately at the 8th and 24th hours of torsion.

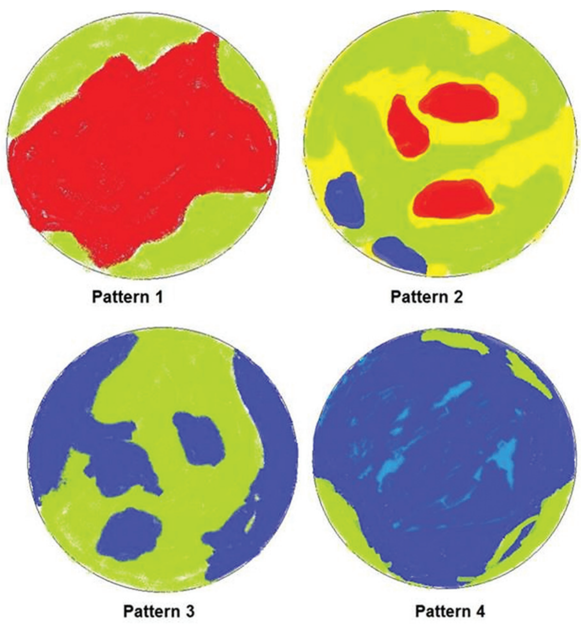
Pathologic Evaluation

Pathologic evaluation of left and right testes that were surgically removed at the 24th hour of torsion was done in the pathology laboratory. Testicular tissues were excised and observed macroscopically. Excised testis tissue samples were fixed and embedded into paraffin. Five-micrometer tissue sections were cut from each slice, glass mounted, and stained with hematoxylin-eosin. All slices were evaluated under a light microscope by a single pathologist with 14 years of experience in a blinded fashion. Testicular tissue injury was scored according to a 4-point grading system proposed by Cosentino et al.[13] Grade 1 showed normal testicular architecture with an orderly arrangement of germinal cells. Grade 2 injury showed less orderly noncohesive germinal cells and closely packed seminiferous tubules. Grade 3 injury showed disordered sloughed germinal cells with shrunken pyknotic nuclei and less distinct seminiferous tubule borders. Grade 4 injury showed seminiferous tubules that were closely packed with coagulative necrosis of the germinal cells.[14]

Statistical Analysis

Statistical analysis was performed with commercially available statistical software (SPSS version 21.0; IBM Corporation, Armonk, NY). Differences between variables

Figure 1. Elasticity patterns on elastography. Pattern 1: the testis is soft with mostly red and green areas. Pattern 2: the testis is moderately soft with a mixture of green and yellow areas. Some areas of hardness may be present (blue), representing less than 10% of testicular parenchyma. Pattern 3: the testis is predominantly hard with blue and green areas. Blue areas account for greater than 50% of the image. Pattern 4: the testis is almost entirely hard, ranging from light blue to dark blue on the elastogram. Blue areas account for almost 90% of the image.



were assessed by Kruskal-Wallis, Mann-Whitney *U*, and Wilcoxon signed rank tests. $P \leq .05$ was defined as significant. The elastographic patterns were compared between the radiologists by the weighted Cohen's κ coefficient. The intraclass correlation coefficient with its 95% confidence interval was used to assess the concordance between the radiologists in terms of strain ratio measurements. Interobserver agreement was categorized as follows: 0 to 0.20, poor; 0.21 to 0.40, fair; 0.41 to 0.60, moderate; 0.61 to 0.80, substantial; and 0.81 to 1.00, almost perfect.[15]

Results

Color Doppler sonography done by radiologist 1 showed no blood flow at both hours and confirmed torsion in the left testes in all torsion groups. Left testes of the sham group and right testes of all groups showed normal blood flow. After Doppler sonography, real-time strain elastography was applied by the radiologists one by one for each rat. Statistical analysis of data regarding elastographic patterns and strain ratios for each radiologist revealed similar results.

Figure 2. Grayscale image (left) and elastogram (right). Pattern 1 in the right testis (circle) and pattern 2 in the left testis (arrows) of a rat were observed at the 8th hour of 360° torsion.

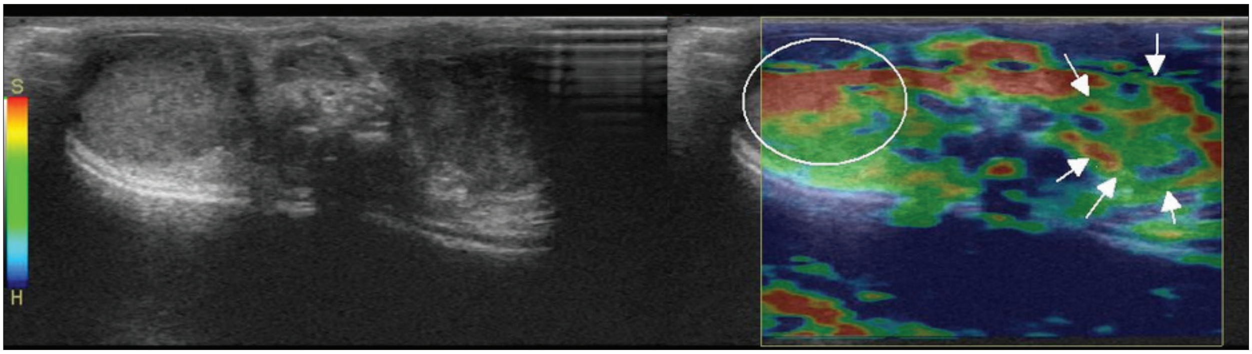


Figure 3. Grayscale image (left) and elastogram (right). Pattern 1 in the right testis (circle) and pattern 4 in the left testis (arrows) of a rat were observed at the 24th hour of 720° torsion.

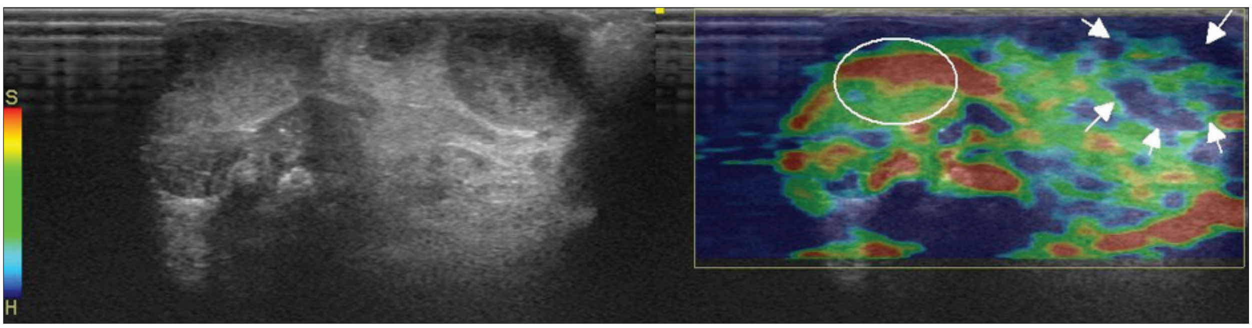
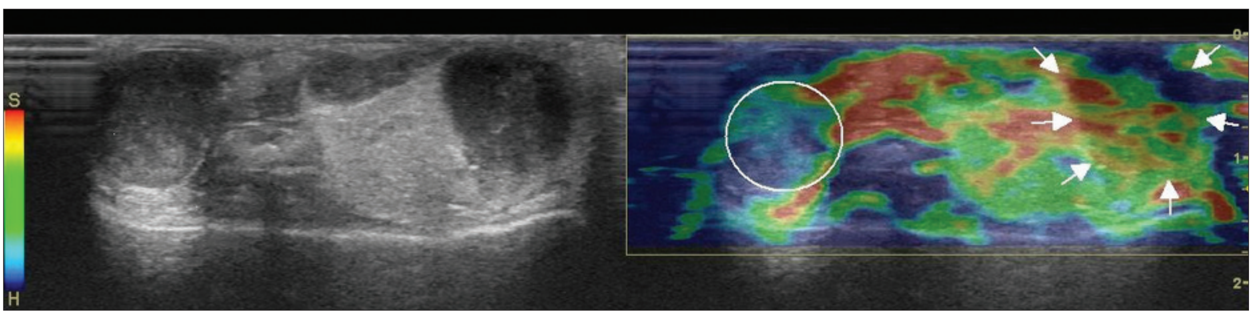


Figure 4. Grayscale image (left) and elastogram (right) showing reversal in patterns at 1080° torsion. Pattern 1 in the left testis (arrows) and pattern 4 in the right testis (circle) of a rat were observed at the 24th hour of 1080° torsion.



According to these results, almost all of the right testes of the rats in groups I, II, and III had pattern 1, but in group IV, right testes had pattern 4 at both the 8th and 24th hours of torsion. There was no statistically significant difference in elastographic patterns of the right testes between groups I, II, and III, but the difference in elastographic patterns of the right testes was significant between group IV and the other groups ($P < .01$). The elastographic pattern of the left testes (experimentally twisted) was consistent with pattern 2 in group II and pattern 3 in group III at the 8th hour of torsion. When evaluated at the 24th hour of torsion, the pattern of the left testes in group II changed into pattern 3, and in group III, it changed into pattern 4, establishing an increase in the hardness of testicular tissue. However, in groups I and IV, elastographic patterns of the left testes did not differ at the 8th and 24th hours of the experiment and were noted as pattern 1, which showed softer tissue properties. The changes in elastographic patterns of the left testes between groups I and II, I and III, and II and III were statistically significant at both hours of torsion ($P < .01$). Changes in the elastographic patterns of the left testes between group IV and groups II and III were also statistically significant at both hours of torsion ($P < 0.01$). The left testes in groups II and III were harder than in group I but softer in group IV at both hours of torsion. The changes in elastographic patterns in groups II and III between the 8th and 24th hours of torsion were also statistically significant ($P < .05$). Table 1 describes the comparison of patterns for right and left testes between groups and within groups at the 8th and 24th hours of torsion.

The differences between strain ratios of groups I, II, and III, and group IV were statistically significant at the 8th and 24th hours of torsion. Also, the differences between strain ratios of groups I and II, groups I and III, and groups II and III were statistically significant at both hours of torsion (Table 2). Strain ratios increased as the torsion increased from 360° to 720°, but at 108°, left testes became softer, and a sudden decrease in strain ratios was observed (Table 2). Although the elastographic patterns of left testes in groups I and IV were similar, strain ratios in group IV were explicitly smaller than in the sham group. Table 2 describes the comparison of strain ratios between groups at the 8th and 24th hours of torsion.

The concordance between the radiologists for elastographic patterns at the 8th hour of testicular torsion was substantial for right testes ($\kappa = 0.72$) and was excellent for left testes ($\kappa = 0.85$). At the 24th hour, concordance was excellent for both right ($\kappa = 0.81$) and left ($\kappa = 0.82$) testes. The concordance between the radiologists for strain ratios was excellent for both testes at both hours of torsion (intraclass correlation coefficients, 0.990 at the 8th hour and 0.987 at the 24th hour).

Table 1. Comparison of Elastographic Patterns for Right and Left Testes Between Groups at the 8th and 24th Hours of Torsion

Group	Right Testes Pattern		Left Testes Pattern	
	8th h	24th h	8th h	24th h
I				
Observer 1	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
Observer 2	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
Average (observers 1 and 2)	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00	1.00 ± 0.00
II				
Observer 1	1.25 ± 0.25	1.12 ± 0.12	2.12 ± 0.22[a]	3.00 ± 0.00[a,b]
Observer 2	1.12 ± 0.12	1.25 ± 0.25	2.00 ± 0.26[a]	2.87 ± 0.12[a,b]
Average (observers 1 and 2)	1.18 ± 0.13	1.18 ± 0.12	2.06 ± 0.17[a]	2.93 ± 0.06,[a,b]
III				
Observer 1	1.00 ± 0.00	1.12 ± 0.12	3.12 ± 0.12[a,c]	4.00 ± 0.00[a,b,c]
Observer 2	1.12 ± 0.12	1.25 ± 0.16	3.25 ± 0.16[a,c]	3.87 ± 0.12[a,b,c]
Average (observers 1 and 2)	1.06 ± 0.06	1.18 ± 0.10	3.18 ± 0.10[a,c]	3.93 ± 0.06[a,b,c]
IV				
Observer 1	4.00 ± 0.00[d]	3.57 ± 0.12[d]	1.12 ± 0.12[e]	1.12 ± 0.12[e]
Observer 2	3.75 ± 0.16[d]	4.00 ± 0.00[d]	1.12 ± 0.12[e]	1.37 ± 0.18[e]
Average (observers 1 and 2)	3.87 ± 0.08[d]	3.93 ± 0.06[d]	1.12 ± 0.08[e]	1.25 ± 0.11[e]

Data are presented as mean ± SEM.
[a] $P < .01$ compared with group I.
[b] $P < .05$ compared with 8th hour of torsion.
[c] $P < .01$ compared with group II.
[d] $P < .01$ compared with groups I, II, and III.
[e] $P < .01$ compared with groups II and III.

According to histopathologic examination of right testes, there was no statistically significant difference between group I and the torsion groups and among the torsion groups (groups II–IV). Most of them were evaluated as grade 1. Percentages of histopathologic grading for right testes in the groups were as follows: 100% grade 1 in group II, 87.5% grade 1 and 12.5% grade 2 in group II, 62.5% grade 1 and 37.5% grade 2 in group III, and 75% grade 1 and 25% grade 2 in group IV. However, according to histopathologic evaluation of the left testes, there were statistically significant differences in the pathologic grades between groups I and III ($P = .002$), I and IV ($P = .001$), II and IV ($P = .001$) and III and IV ($P = .001$). Pathologically severe necrosis (grade 4) was observed in most of the left testes in group IV, where the testes were softer than the testes of the other groups with manual palpation. Percentages of histopathologic grading for left testes in the groups were as follows: 85.7% grade 1 and 14.3% grade 2 in group I, 50.0% grade 1, 37.5% grade 2, and 12.5% grade 3 in group II, 75.0% grade 2 and 25.0% grade 3 in group III, and 37.5% grade 3 and 62.5% grade 4 in group IV. Figure 5 shows the pathologic scores of both testes according to the grading system of Cosentino et al.[13] Figure 6 shows histopathologic samples of grades from the left testes of the cases.

Table 2. Comparison of Strain Ratios Between Groups at the 8th and 24th Hours of Torsion

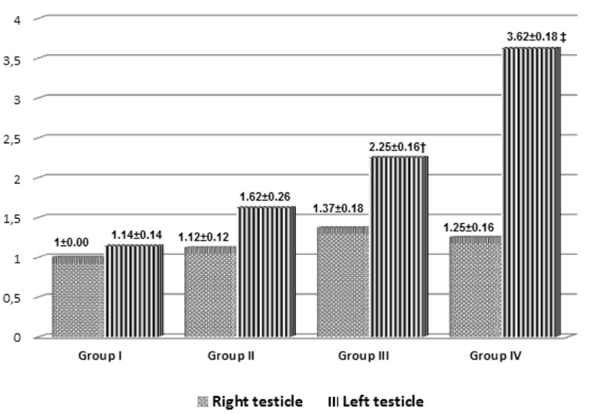
	Strain Ratio (Left/Right Testis)	
Group	**8th h**	**24th h**
I		
Observer 1	1.07 ± 0.31	0.93 ± 0.15
Observer 2	1.07 ± 0.29	0.88 ± 0.14
Average (observers 1 and 2)	1.07 ± 0.29	0.90 ± 0.14
II		
Observer 1	1.61 ± 0.34[a]	2.28 ± 0.61[b]
Observer 2	1.53 ± 0.23[a]	2.31 ± 0.68[b]
Average (observers 1 and 2)	1.57 ± 0.28[a]	2.30 ± 0.62[b]
III		
Observer 1	3.48 ± 0.23[b,c]	3.19 ± 0.70[b,d]
Observer 2	3.35 ± 0.36[b,c]	3.12 ± 0.51[b,d]
Average (observers 1 and 2)	3.41 ± 0.30[b,c]	3.15 ± 0.59[b,d]
IV		
Observer 1	0.23 ± 0.12[b,e]	0.42 ± 0.09[b,e]
Observer 2	0.21 ± 0.07[b,e]	0.41 ± 0.12[b,e]
Average (observers 1 and 2)	0.22 ± 0.96[b,e]	0.42 ± 0.10[b,e]

Data are presented as mean ± SEM.
[a] $P < .05$ compared with group I.
[b] $P < .01$ compared with group I.
[c] $P < .01$ compared with group II.
[d] $P < .05$ compared with group II.
[e] $P < .01$ compared with groups II and III.

Discussion

The results of this experimental study showed that necrosis in testicular torsion causes softer elastographic patterns with very small strain ratios, and when necrosis occurs in the torsion site, the contralateral testis is also affected, representing harder tissue properties on elastograms with quite high strain ratios. According to our results, the left testes gradually became harder when the torsion increased from 360° to 720° and the duration of torsion increased from 8 to 24 hours, but they became softer when the torsion increased to 1080°. Strain ratios were approximately 1.0 in the sham group and 3.0 to 3.5 in the 720° torsion group, but elastographic patterns and strain ratios reversed in group IV. Left testes in group IV were coded green and red, and right testes were mostly blue. The strain ratio in group IV was less than 1.0, indicating low stiffness in tissue behavior. This change in group IV can be explained by pathologically proven severe necrosis, which was only seen in most of the left testes of this group. We think that edema, which is the first change in testicular torsion by obstruction of venous outflow, causes hardness in the tissue, which presents as mostly green and blue on real-time strain elastography. However, with a longer duration, especially in delayed cases or with increasing torsion degrees, arterial inflow is obstructed after venous obstruction and causes necrosis, which results in softer tissue characteristics, represented as a mixture of red and green areas on real-time strain elastography. Strain ratios also reflected this fact in this study. Higher strain ratios in groups II and III indicated higher

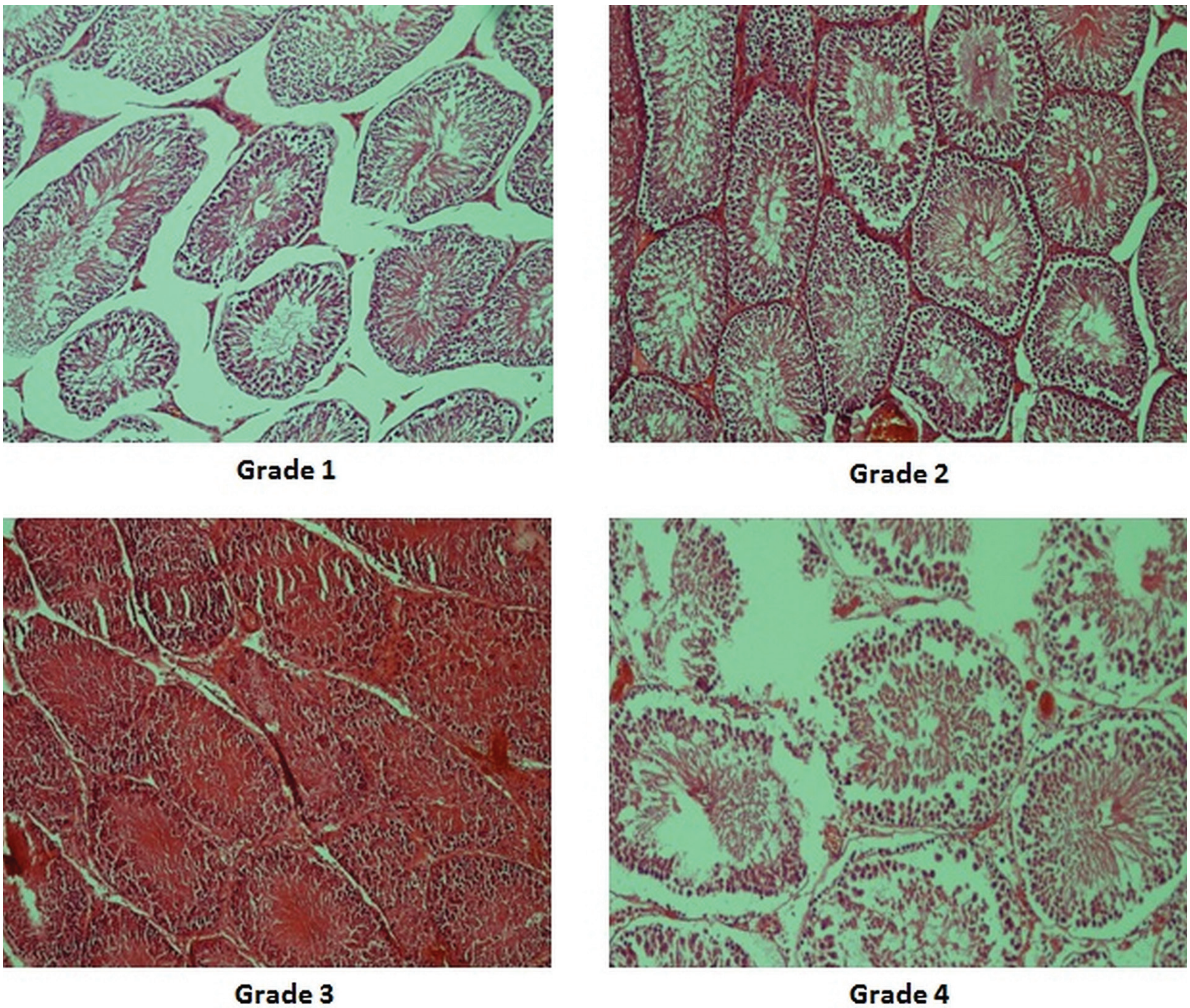
Figure 5. Pathologic scores of both testes in all groups according to the grading system of Cosentino et al.[13] Data are presented as mean ± SEM, †$P < .01$ compared with group I; ‡$P < .01$ compared with groups I, II, and III.



stiffness in the tissue, and lower strain ratios in group IV indicated lower stiffness. Therefore, according to these findings, we can give opinions about the duration or probable torsion degree by observing elastographic patterns and strain ratios and can guide surgeons in their choice of the surgical approach by giving opinions about the salvageability of the testis. In group IV, right testes were almost entirely blue, with prominent hardness on real-time strain elastography, compared with right testes of other torsion groups. Hence, we concluded that the contralateral testes were affected more when the degree of torsion increased, and this change in the elastograms represented edema. These results showed us that the torsion degree plays an important role in the elasticity of tissue and is related to pathologic results.

Testicular torsion is an ischemic injury to testicular cells that occurs frequently during the peripubertal period.[16] Testicular dysfunction and infertility are important complications, which gradually increase as the degree and duration of torsion increase; therefore, prompt diagnosis and surgical exploration are required.[17,18] Hemorrhagic infarction between 4 and 8 hours and complete necrosis after 24 hours in the twisted testis have been reported.[19] Also, various experimental studies also referred to damage to the

Figure 6. Hematoxylin-eosin staining (original magnifications ×100 and ×200). Grade 1 shows a normal testicular structure with regularly arranged germinal cells. Grade 2 shows mild interstitial edema and hemorrhage with noncohesive germinal cells. Grade 3 shows seminiferous tubules with nondistinct borders and apparent hemorrhage. Grade 4 shows coagulative necrosis of the germinal cells.



contralateral testis.[17,18,20] Immunologic mechanisms, reflex vasoconstriction, and decreased blood flow to the contralateral testis have been shown to be the theories for this kind of damage.[18] In this study, we found that elastographic patterns and strain ratios reversed in group IV (1080° torsion) in both testes at both hours of torsion. When pathologically compared with the other torsion groups, the only difference in group IV was the obvious necrosis in left testes. Hence, necrosis in the testicular tissue is the only explanation for this reversal in pattern and strain ratios. In a previous study, cervical lymph nodes were evaluated by real-time strain elastography, and intranodal necrosis was reported to force the investigators to modify their scoring system, in which the necrotic part was shown by less stiffness and high strain areas.[12] We also think that necrosis inside the testicular tissue caused softer elastographic behavior, which was represented by green and red areas and very low strain ratios. Necrosis occurs when the torsion degree increases, and contralateral testes are affected more at torsion of greater than 720°. These findings, unlike Doppler sonography, which showed absent blood flow in all torsion groups, suggest that the testes are not salvageable at torsion of greater than 720° and may be rescued by surgical detorsion at torsion of less than 720°. The only downside of this finding is that the same elastographic pattern was also observed in the nonoperated group (group I), which might be confusing. However, the strain ratio, which was calculated at less than 1.0 in group IV and very much smaller than that of group I, was more effective here in distinguishing between necrotic tissue and a normal testicular texture.

The first and common radiologic method used in testicular torsion evaluation is sonography combined with color Doppler imaging.[21–24] In testicular torsion, no blood flow is seen on Doppler sonography. However, this classic finding depends on the duration and degree of torsion.[21,23] In the early phases, testicular venous dilatation may cause increased blood flow in the parenchyma, which can lead to a wrong diagnosis.[23] Also, prepubertal normal testicular vasculature is inherently hard to visualize even with power Doppler sonography, creating a risk of a false-positive diagnosis. On the contrary, intermittent testicular torsion may lead to a false-negative result.[21,22,25] These diagnostic difficulties sometimes cause misdiagnosis and unnecessary surgical procedures. In our study, color Doppler sonography also showed no blood flow in all torsion groups, which did not help us decide whether the testes were salvageable.

There are reports showing that scintigraphy and Doppler sonography have similar diagnostic sensitivity in testicular torsion.[22,26] However, scintigraphy involves a risk of ionizing radiation, is expensive, and may not be performed at a proper time, causing delays in diagnosis.[25,27] Magnetic resonance imaging (MRI) is another method that can be done with or without contrast enhancement.[28] In an experimental study, it was stated that torsion caused ipsilateral hypoperfusion, resulting in decreased gadolinium uptake on MRI.[29] It was reported that contrast-enhanced subtraction MRI could provide information about testicular perfusion in testicular torsion, which shows no or little contrast enhancement regarding hemorrhagic necrosis.[30] However, MRI is expensive, not widely available, takes longer to apply, and is difficult to do in childhood because of the need for anesthesia to keep the child immobile during the examination. Thus, testicular torsion, which is seen mostly in childhood, may not be effectively evaluated by MRI in the proper time.

Real-time strain elastography is a relatively new technique that measures tissue stiffness. A stressing force as compression is applied, and strain, which is displacement of the tissue as a response to a stress, is produced.[8] Real-time strain elastography gives information about tissue hardness marked by different colors as red, green, yellow, and blue. Mostly, blue represents hard and sclerotic parts, and red represents softness in the tissues.[31] In this study, we also set the color mapping as blue for the hardest and red for the softest tissue parts. According to these settings, patterns showed higher tissue stiffness, and strain ratios gradually increased at 360° and 720° of torsion, but reversal was seen at 1080° at both times. After pathologic evaluation, necrosis was observed in these testes, which showed us that damage at 1080° is irreversible. This study also revealed that the contralateral testes are also affected during torsion. According to our study, although no pattern change on elastography was observed in the contralateral testes in groups II and III, they were coded mostly blue on elastography in group IV, indicating harder tissue behavior at both hours. Therefore, we think that this kind of damage (torsion >720°) is irreversible, in which softer patterns resulting from evident necrosis are seen in testes with torsion and harder patterns are observed in the contralateral testes. Elastographic patterns are also useful for deciding whether a testis can be surgically saved in suspected cases when Doppler sonography is confusing. Doppler sonography is challenging in cases of partial torsion which corresponds to variable torsion degrees ranging between 180° and 720°.[3,32] In these cases, elastography may be more useful than Doppler sonography for deciding about the viability and salvageability of the testis via elastographic patterns and strain ratios.

This study had some limitations. First, preliminary results of our experimental study show that elastography can be an adjunct method in the evaluation of testicular torsion, but we cannot know the real reflection of the results on humans. Therefore, the results of this study should also be observed in clinical cases. Second, pathologic evaluation was only achieved at 24th hour because we aimed to compare results of testicular torsion in the same rats at both hours. Third, we did not evaluate the testicular tissue at a time point earlier than 6 hours. However, most of testicular torsion cases reach the hospital in a late period (>6 hours after the onset of symptoms), causing confusion in the diagnosis and determination of salvageability. These factors affected our choice 8 and 24 hours as time points.

In conclusion, our experimental study shows that real-time strain elastography can be an adjunct to Doppler sonography in the evaluation of tissue in testicular torsion. According to an elastographic evaluation, it is possible to say that testes twisted greater than 720° with long-lasting (>6-hour) torsion periods possibly have necrosis, showing lower stiffness on elastography. These testes are nonviable and not salvageable; therefore, they should be removed surgically. When reversed elastographic patterns are observed, which is pattern 1 in a twisted testis and pattern 4 in the contralateral testis, damage is irreversible on the twisted side, and the contralateral testis is also affected by the ischemic situation. When Doppler sonography is inconclusive in partial testicular torsion, elastographic patterns and strain ratios become important in showing testicular viability, and elastography may replace Doppler sonography as a main radiologic tool. These results show that real-time strain elastography can guide surgeons in their choice of the surgical procedure for testicular torsion. However, our work was an experimental study; therefore, these results need to be proven by clinical cases in the long run.

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