Kocatepe Tıp Dergisi
Kocatepe Medical Journal
24:1-7 / Ocak 2023 Sayısı

ARAŞTIRMA YAZISI / RESEARCH ARTICLE

GLOKOM HASTALARINDA SHEAR WAVE ELASTOGRAFİ BULGULARI

SHEAR WAVE ELASTOGRAPHY FINDINGS IN GLAUCOMA PATIENTS

Azad HEKİMOĞLU[1], Onur ERGUN[1], Aysun SANAL DOĞAN[2], Şule Berk ERGUN[3], Mutlu ACAR[2], Canan GÜRDAL[2], Baki HEKİMOĞLU[1]

[1]Dışkapı Eğitim Aratırma Hastanesi Radyoloji Kliniği
[2]Dışkapı Eğitim Araştırma Hastanesi Göz Hastalıkları Kliniği
[3]Ankara Şehir Hastanesi Göz Hastalıkları Kliniği

ÖZET

AMAÇ: Amacımız glokom hastalarında shear wave elastography (SWE) ile gözün farklı bölgelerindeki sertlik değerlerinin ölçülmesi ve sonuçlarının sağlıklı gözlerle karşılaştırılarak oküler kompartmanların elastisitesinde bir değişiklik olup olmadığının araştırılmasıdır.

GEREÇ VE YÖNTEM: Bu çalışmada açık açılı glokomlu 12 hasta ile 32 sağlıklı gönüllüyü SWE donanımlı ultrasonografi cihazı kullanarak karşılaştırdık. Tüm hastalarda sadece sağ göz değerlendirildi. İlk olarak, göz küresi genellikle B-modunda incelendi. Daha sonra arka segmentte optik sinir başı, retro-orbital sinir, sklera-retina kompleksi ve retro-orbital yağ dokusunun sertlik değerleri ile gözün ön segmentinde kornea, lens ve ön kamara sertlik değerleri kiloPaskal cinsinden ölçüldü. SWE ile ve her iki grup istatistiksel olarak karşılaştırıldı.

BULGULAR: Gözün farklı bölgelerinde yapılan ölçümlerde kaydedilen sertlik değerleri açısından hasta ve kontrol grupları arasında istatistiksel olarak anlamlı bir farklılık bulunmadı.

SONUÇ: SWE kolay uygulanabilir bir yöntem olmasına rağmen, glokom ve kontrol grupları arasında anlamlı bir fark bulunmadı. Ancak bu çalışma ile normal kişilerde gözün farklı bölgeleri için referans değerler belirlenmiştir.

ANAHTAR KELİMELER: Göz, Glokom, Shear wave elastografi, Sertlik

ABSTRACT

OBJECTIVE: Our aim is to measure the stiffness values in different regions of the eye with shear wave elastography (SWE) in patients with glaucoma and to compare the results with healthy eyes to investigate whether there is a change in the elasticity of the ocular compartments in glaucoma patients.

MATERIAL AND METHODS: In this study, we compared 12 patients with open-angle glaucoma and 32 healthy volunteers using an SWE-equipped ultrasonography device. Only the right eye was evaluated in all patients. First, the eye globe was generally examined in B-mode. Then, the stiffness values of the optic nerve head, retro-orbital nerve, sclera-retina complex and retro-orbital adipose tissue in the posterior segment and the stiffness values of the cornea, lens and anterior chamber in the anterior segment of the eye were measured with SWE in kiloPascal and both groups were compared statistically.

RESULTS: No statistically significant differences were found between the patient and control groups in terms of the stiffness values recorded in the measurements performed in different parts of the eye.

CONCLUSIONS: Although SWE is an easily applicable method, no significant differences were found between glaucoma and control groups. However, thanks to this study, reference values for different parts of the eye in normal individuals have been determined.

KEYWORDS: Eye, Glaucoma, Shear-wave elastography, Stiffness

Geliş Tarihi / Received: 31.03.2021
Kabul Tarihi / Accepted: 21.02.2022
Yazışma Adresi / Correspondence: Dr. Azad HEKİMOĞLU
Dışkapı Eğitim Araştırma Hastanesi Radyoloji Kliniği
E-mail: azadhekimoglu@gmail.com
Orcid No (Sırasıyla): 0000-0001-7853-019X, 0000-0002-0495-0500, 0000-0002-7401-8903, 0000-0002-6698-8440, 0000-0002-0300-7350, 0000-0003-1834-7216, 0000-0002-1824-5853
Etik Kurul / Ethical Committee: Ankara Dışkapı Eğitim Araştırma Hastanesi Etik Kurulu (2015.19/19).

INTRODUCTION

The inflammatory and neoplastic changes in the soft tissues are related to the changes in their elasticity (1). Therefore, elasticity and stiff -ness are important factors in the differential diagnosis. Sonoelastography is a non-invasive method, which has been used recently in the evaluation of the elasticity of the biological tissues and started to be used in the thyroid, lymph node, breast, testis, muscle, and abdominal solid organ diseases (2 - 9).

There are four main types of sonoelastography techniques, which are compression (or strain) elastography, transient elastography, tension elastography and shear-wave elastography (SWE), each with its own advantages and disadvantages (10). In the frequently used strain elastography, stress is applied to the tissue with repeated manual compression of the transducer, and the degree of deformation in the lesion compared to the surrounding normal tissue is measured, and depicted in color. Therefore, with this technique, obtaining and interpreting the data from elasticity images are largely dependent on the experience of the investigator and it was found to show inter-observer variance (11, 12). In contrast to strain elastography, SWE uses an acoustic radiation force impulse created by a focused ultrasound beam, which allows measurement of the speed of shear waves within the tissue to quantify its stiffness in kiloPascals (13, 14). As no pressure on the tissue is required in this method, and the elasticity of the tissue can be measured quantitatively in kiloPascals without the need for comparison with the surrounding tissue, this method was considered to be more advantageous for our study (15).

Glaucoma is one of the most common causes of blindness worldwide (16, 17). It is well known that glaucoma has a complex pathophysiology and a multifactorial etiology, and is an optic neuropathy whose severity increases with the increase in intraocular pressure (18, 19). In glaucomatous optic neuropathy, loss of the retinal nerve layer, loss of the focal and generalized neuroretinal rim, optic disc hemorrhage, and parapapillary atrophy can be observed (20 - 22).

The aim of our study is to investigate whether there is a change in the elasticity of the ocular compartments caused by high intraocular pressure in glaucoma patients with SWE.

MATERIAL AND METHODS

Our study consists of two groups including patients with glaucoma and healthy volunteers. The patient group comprised 12 patients (8 males, 4 females) who were diagnosed with open-angle glaucoma in the ophthalmology clinic of our hospital with a mean age of 62 years (range: 44-77). The control group consisted of 32 healthy volunteers (14 males, 18 females) with a mean age of 57 years (range: 20-71). All patients with glaucoma were under topical antiglaucoma treatment and had a history of glaucoma for 1 to 10 years (mean value: 5.4 years). In the patient group, the cup-to-disc ratio (CDR), which is an indicator of the severity of the disease, was between 0.5 and 0.9 (mean value: 0.63). Consents of all individuals in the patient and control groups were obtained before including them in the study. Those with other known ophthalmologic, metabolic, or endocrinologic (DM, goiter, etc.) diseases were excluded from the study. In addition, patients who underwent ophthalmologic surgery or patients with a trauma history were not included in the study.

Ethical Committee

Our study is a prospective research study, was conducted according to the ethical standards of the Declaration of Helsinki, and approved by the Institutional Ethics Committee (Ankara Diskapi Yildirim Beyazit Training and Research Hospital) (2015.19/19).

Elastography Technıque

All patients included in the study were evaluated with an ultrasonography device (GE Logiq E9) using a 9L linear probe. The right eye was evaluated in all patients. The eyes of the patients were closed while the patients were in a supine position, and a copious amount of gel was put on the probe. Then, without applying additional pressure, the probe was placed on the upper eyelid of the closed eye.

The patients were instructed not to open their eyes and not to move their eyes while looking at a fixed point during the procedure. All measurements were performed by a single radiologist who has 5-year experience in ultrasonographic examination. All measurements were repeated three times, and the mean of these three measurements was calculated. First, the globe of the eye was examined generally in B-mode. Following the general examination, the image of the posterior segment of the eye was constructed in a way that would include the retro-orbital nerve and the retro-orbital adipose tissue. As shown in **Figure 1a**, in the posterior segment of the eye, the cursor of the region of interest (ROI) was placed on the optic nerve head, retro-orbital nerve, sclera-retina complex and retro-orbital adipose tissue respectively, and the stiffness values were automatically measured in kiloPascals and recorded. Then, the image of the anterior segment of the eye was constructed, and as seen in **Figure 1b**, the cursor of the ROI was placed on the cornea, lens and anterior chamber respectively and the stiffness values were automatically measured in kiloPascals and recorded. Since it is not possible to distinguish between the retina, choroid, and sclera by using ultrasonography, we examined them as a whole under the term "sclera-retina complex" (23).

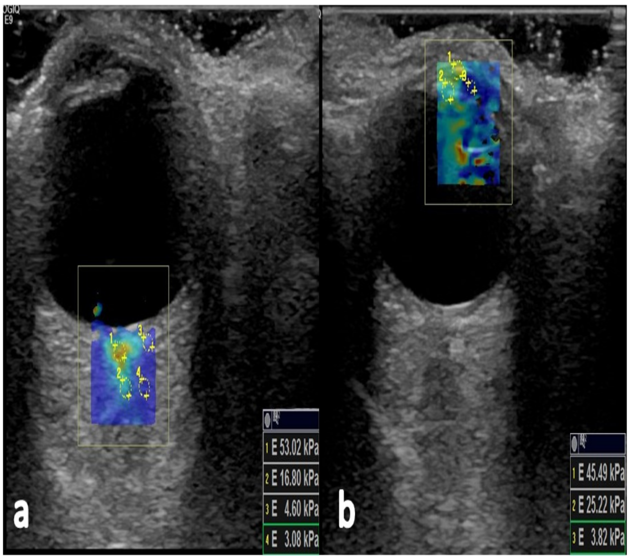

Figure: 1a) Evaluation of the posterior segment of the eye: 1-optic nerve head; 2-retrobulbar nerve; 3-sclera-retina complex; 4-retrobulbar adipose tissue. **1b)** Evaluation of the anterior segment of the eye: 1-cornea; 2-lens; 3-anterior chamber.

Statistical Analysis

Data analysis was performed by using SPSS for Windows, version 11.5 (SPSS Inc., Chicago, IL, United States). Whether the distributions of continuous variables were normal or not was determined by the Shapiro Wilk test. Continuous variables were shown as mean ± SD. The number of cases and percentages were used for nominal data. The mean differences between the control and glaucoma groups were compared by Student's t-test. Nominal data were analyzed by Pearson's Chi-square test. A p-value less than 0.05 was considered statistically significant.

RESULTS

Based on the demographic characteristics of the patients, there were no statistically significant differences between the glaucoma group and the control group in terms of mean age and distribution of males and females (p=0.104, p=0.176, respectively) **(Table 1)**.

Table 1: Demographical and clinical characteristics for control and glaucoma groups

Variables	Control (n=32)	Glaucoma (n=12)	p-value
Age (years)	57.1±7.1	62.0±8.4	0.104†
Gender			0.176‡
Male	14 (43.8%)	8 (66.7%)	
Female	18 (56.2%)	4 (33.3%)	
Optic nerve head	42.5±7.0	41.7±6.2	0.743†
Retro-orbital nerve	24.0±5.2	23.7±6.5	0.901†
Sclera-retina complex	4.77±1.86	4.77±1.84	0.997†
Retro-orbital fat	2.54±1.05	2.70±0.89	0.662†
Cornea	43.1±7.8	38.2±11.8	0.200†
Lens	25.3±6.8	23.1±5.8	0.348†
Anterior camera	3.8±1.1	3.7±1.4	0.826†

† Student's t test, ‡ Pearson's Chi-square test.

The mean stiffness values of the right eyes of the 32 healthy volunteers were: 42.5±7.0 kiloPascals at the optic nerve head, 24.0±5.2 kiloPascals at the retro-orbital nerve, 4.77±1.86 kiloPascals at the sclera-retina complex, 2.54±1.05 kiloPascals at the retro-orbital adipose tissue, 43.1±7.8 kiloPascals at the cornea, 25.3±6.8 kiloPascals at the lens and 3.8±1.1 kiloPascals at the anterior chamber (Table 1).

The mean stiffness values of the right eyes of 12 patients were: 41.7±6.2 kiloPascals at the optic nerve head, 23.7±6.5 kiloPascals at the retro-orbital nerve, 4.77±1.84 kiloPascals at the sclera-retina complex, 2.70±0.89 kiloPascals at the retro-orbital adipose tissue, 38.2±11.8 kiloPascals at the cornea, 23.1±5.8 kiloPascals at the lens and 3.7±1.4 kiloPascals at the anterior chamber (Table 1).

Based on the posterior segment examination with SWE, there were no statistically significant differences between the glaucoma group and the control group in terms of the stiffness values of the right optic nerve head, retro-orbital nerve, sclera-retina complex, and retro-orbital adipose tissue (p=0.743; p=0.901; p=0.928; p=0.354, respectively) (Table 1).

Based on the anterior segment measurements of the eye with SWE, cornea, lens and anterior chamber stiffness values of glaucoma, and control group were statistically similar (p=0.200, p=0.348, p=0.826, respectively) (Table 1).

DISCUSSION

Elastography is a diagnostic tool which measures the elasticity and stiffness of the tissues and is used in the differential diagnosis between pathological (malign or benign) and normal tissues (24). The elasticity of the pathological tissues is less compared to the normal tissues. It is known that there is scleral rigidity in glaucoma patients (25). Unlike other organs, the eye has a heterogeneous structure, and the application of elastography is difficult. However, in a study conducted by Detorakis et al., strain elastography was shown to be usable in ocular tissues (26).

The number of studies on the sonoelastrography of the eye is rather limited compared to other organs. The first studies were performed on patients with vision loss (26, 27). In the strain elastography study on patients with vision loss secondary to glaucoma which was performed by Vural et al., it was found that orbital elastography can distinguish the strain values of the optic nerve and retrobulbar adipose tissue, and they stated that this can be used in other prospective studies (27). Likewise, Detorakis et al. reported that ultrasound elastography can be used for the evaluation of various ophthalmic pathological conditions for the ocular and periocular tissues (26). While the use of strain elastography is limited to compressible, superficial tissues, SWE enables the evaluation of more deeply located structures such as liver and prostate. This feature becomes more significant in the ocular use of elastography since applying pressure on the eye with the ultrasound probe causes more dramatic changes in the anterior segment of the eye, which is more superficial than the posterior segment (28). SWE is the new-generation elastography method, which produces low-frequency and low-speed waves perpendicular to the tissue and quantitatively measures the elasticity of the tissue (29). With this method, the elasticity of an area can be quantitatively measured in kiloPascals with the acoustic impulses sent to the area of interest (30). One of the most important advantages of the SWE is that, unlike strain elastography, the application of compression or pressure is not required (28).

Moreover, applying pressure to the eye during the examination can be uncomfortable for the patients. Thus, in our study, we believed that SWE was more easily applicable to the eye. The first ocular use of SWE in the literature was in 2014, on the rabbit eye. Detorakis et al. investigated the elasticity of the ciliary muscles and the lens during contraction (using a cholinergic agonist) and relaxation (using a cholinergic antagonist) (28).

Glaucoma is a multifactorial and progressive optic neuropathy, characterized by the destruction of the retinal ganglion cells, loss of visual field and the cupping of the optic nerve head. High intraocular pressure has been considered one of the important factors that play a prominent role in the initiation or progression of glaucoma and loss of the retinal ganglion cells (31). It is an insidious disease with the gradual loss of vision and is one of the main causes of secondary blindness (32). It is often difficult to detect the development of glaucoma, but there are physical and morphological differences between glaucoma patients and healthy individuals. In this study, our objective was to identify the physical changes in glaucoma patients using SWE.

We investigated the elasticity of the optic nerve head, retro-orbital nerve, sclera-retina complex, and retro-orbital adipose tissue in the posterior segment of the eye in 12 glaucoma patients and

32 healthy controls. In addition, the elasticities of the cornea, lens, and anterior chamber in the anterior segment of the eye were measured, which was not performed previously in the literature, and the results of the two groups were statistically compared. Based on the results, in the posterior segment of the eye, the stiffness of the optic nerve head was the highest, and the stiffness of the retro-orbital adipose tissue was the lowest. Also, in the study conducted by Pekel et al., the most elastic (soft) part of the eye was found to be the retro-bulbar adipose tissue, and the least elastic (stiff) part was the optic nerve head (33). In the study by Vural et al., which used strain elastography on patients with glaucomatous visual loss, a significant difference was observed between the optic nerve head and retro-orbital adipose tissue; however, the comparison between normal and atrophic optic nerve was not made (27). In the previous studies conducted using strain elastography, one of the structures whose elasticity was evaluated was the anterior and posterior vitreous (26, 27). However vitreous stiffness could not be measured with SWE in our study. The tissue with the highest stiffness at the anterior segment of the eye was the cornea. We found that the lens was more elastic than the cornea, and the anterior chamber was the most elastic part of the anterior segment of the eye.

So far, there is only one study on glaucoma which used SWE, and it evaluated the distal end of the optic nerve, the distal part of the optic nerve, and the nasal and temporal parts of the perineural sclera (23). In our study, these parameters correspond to the optic nerve head, retro-bulbar nerve, and sclera-retina complex indicated with numbers 1, 2, and 3 respectively in Figure 1. In the aforementioned study, it was found that in patients with glaucoma, the stiffness increased in all these parts compared to the control group, and the difference was statistically significant. However, in our study, the difference between the two groups in terms of stiffness was not significant. In the aforementioned study, the mean CDR value was 0.53 in the glaucoma group. In our study, the same value was 0.63. Furthermore, treatment duration was less than 3 years for almost half of the glaucoma patients while the mean duration of treatment was 5.4 years in our study. In other words, it can be said that glaucoma was more advanced in our patients, and the duration of the disease was longer. Therefore, it was not possible to explain our results with the stage or duration of the disease. Obviously, the relatively small number of patients in our study may be the reason behind our results. Indeed, Dikici et al. reported that even though considerable differences were noted between glaucomatous and normal eyes in general, an overlap of stiffness values between patients with glaucoma and healthy controls was noticed (23). Also, according to the results of the study conducted by Agladioglu et al., the elasticity index of the optic disc was higher than the optic nerve, which was similar to our study (34).

Similar to our study, in the elastography study by Agladioglu et al. on glaucoma patients, no significant difference was detected between the control group and glaucoma group in terms of the stiffness of the optic nerve, optic disk, retina-choroid-sclera complex, retrobulbar adipose tissue and anterior-posterior vitreous (34). However, they the authors used the strain elastography method instead of SWE in their study. They attributed the lack of significant difference to the fact that the disease may be in its early stages and that the patients were under treatment. In another study by Unal et al., the ratio of the optic nerve head to the orbital adipose tissue and the ratio of the optic nerve head to the lateral rectus muscle was measured in glaucoma patients and the control group, and a statistically significant increase was found in the stiffness value of the optic nerve head in glaucoma patients (35). Although we could not find any statistically significant difference between glaucoma patients and the control group, similar to this study stiffness value of the optic nerve head was more than retrobulbar optic nerve and retroorbital adipose tissue.

The major limitation of our study was the small size of the patient group, and the other limitation was the lack of an eye-specific ultrasonography probe for a superficial, small and sensitive organ.

Based on the hypothesis that increased intraocular pressure in glaucoma can cause changes in the elasticity of different parts of the eye, we aimed to determine the changes using SWE. However, against our expectations, we were not able to determine a statistically significant difference between glaucoma and control groups. Because there are studies in the literature with contradicting results, it is clear that there is a need for further studies with a larger sample size. On the other hand, we believe that the reference values obtained from the important structures localized at the anterior and posterior segments of the eye, particularly in the control group comprising 32 healthy volunteers, can be used in prospective studies on various ophthalmologic diseases.

REFERENCES

1. Bhatia KS, Lee YY, Yuen EH, Ahuja AT. Ultrasound elastography in the head and neck. Part I. Basic principles and practical aspects. Cancer Imaging. 2013;13:253-9.

2. Ophir J, Cespedes I, Ponnekanti H, Yazdi Y, Li X. Elastography: a quantitative method for imaging the elasticity of biological tissues. Ultrason Imaging.1991;13:111-34.

3. Ghajarzadeh M, Sodagari F, Shakiba M. Diagnostic accuracy of sonoelastography in detecting malignant thyroid nodules: a systematic review and meta-analysis. AJR Am J Roentgenology. 2014;202:379-89.

4. Bhatia KS, Cho CC, Tong CS, et al. Shear wave elasticity imaging of cervical lymph nodes. Ultrasound Med Biol. 2012;38:195-201.

5. Gong X, Xu Q, Xu Z, Xiong P, Yan W, Chen Y. Real-time elastography for the differentiation of benign and malignant breast lesions: a meta-analysis. Breast Cancer Res Treat. 2011;130:11-8.

6. Hekimoglu A, Tatar IG, Ergun O, Turan A, Aylı MD, Hekimoglu B. Shear wave sonoelastography findings of testicles in cronic kidney disease patients who undergo hemodialysis. Eurasian J Med. 2017;49:12-5.

7. Botar Jid C, Vasilescu D, Damian L, Dumitriu D, Ciurea A, Dudea SM. Musculoskeletal sonoelastography. Pictorial essay. Med Ultrason. 2012;14:239-45.

8. Sandulescu L, Rogoveanu I, Gheonea IA, Cazacu S, Saftoiu A. Real-time elastography applications in liver pathology between expectations and results. J Gastrointestin Liver Dis. 2013;22:221-7.

9. Cochlin DL, Ganatra RH, Griffiths DFR. Elastography in the detection of prostatic cancer. Clin Radiol. 2002;57:1014-20.

10. Taljanovic MS, Gimber LH, Becker GW, et al. Shear-Wave Elastography: Basic physics and musculoskeletal applications. Radiographics. 2017;37: 855-70.

11. Burnside ES, Hall TJ, Sommer AM, et al. Differentiating benign from malignant solid breast masses with US strain imaging. Radiology. 2007;245:401-10.

12. Chang JM, Moon WK, Cho N, Kim SJ. Breast mass evaluation: factors influencing the quality of US elastography. Radiology. 2011;259:59-64.

13. Cosgrove DO, Berg WA, Doré CJ, et al. Shear wave elastography for breast masses is highly reproducible. Eur Radiol. 2012;22:1023-32.

14. Sarvazyan A. P., Rudenko, O. V., Swanson, S. D., Fowlkes, J. B., & Emelianov, S. Y. Shear Wave elasticity imaging: a new ultrasonic technology of medical diagnostics. Ultrasound in Medicine & Biology .1998;24:1419-35.

15. Bercoff J, Tanter M, Fink M. Supersonic shear imaging: a new technique for soft tissue elasticity mapping. IEEE Trans Ultrason Ferroelectr Freq Control. 2004;51:396-409.

16. Chan EW, Li X, Tham YC, et al. Glaucoma in Asia: regional prevalence variations and future projections. Br J Ophthalmol 2016;100:78-85.

17. Zetterberg M. Age-related eye disease and gender. Maturitas. 2016;83:19-26.

18. Mastropasqua R, Fasanella V, Agnifili L, et al. Advance in the pathogenesis and treatment of normal-tension glaucoma. Prog Brain Res. 2015;221:213-32.

19. Casson RJ, Chidlow G, Wood JP, Crowston JG, Goldberg I. Definition of glaucoma: clinical and experimental concepts. Clin Experiment Ophthalmol. 2012;40:341-9.

20. Tuulonen A, Airaksinen PJ. Initial glaucomatous optic disk and retinal nevre fiber layer abnormalities and their progression. Am J Ophtalmol. 1999;111:485-90.

21. Drance SM. Disc hemorrhages in the glaucomas. Surv Ophthalmol.1989;33:331-7.

22. Jonas JB, Naumann GO. Parapapillary chorioretinal atrophy in normal and glaucoma eyes. II. Correlations. Invest Ophthalmol Vis Sci. 1989;30:919-26.

23. Dikici AS, Mihmanli I, Kilic F, et al. In vivo evaluation of the biomechanical properties of optic nerve and peripapillary structures by ultrasonic shear wave elastography in glaucoma. Iran J Radiol. 2016;13: e36849.

24. Barr RG, Destounis S, Lackey LB, Svensson WE, Balleyguier C, Smith C. Evaluation of breast lesions using sonographic elasticity imaging: a multicenter trial. J Ultrasound Med. 2012;31:281-7.

25. Agrawal KK, Sharma DP, Bhargava G, Sanadhya DK. Scleral rigidity in gloucoma, before and during topical antiglaucoma drug therapy. Indian J Ophtalmol. 1991; 39:85-6.

26. Detorakis ET, Drakonaki EE, Tsilimbaris MK, Pallikaris IG, Giarmenitis S. Real-Time Ultrasound Elastographic Imaging of Ocular and Periocular Tissues: A Feasibility Study. Ophtalmic Surgery, Lasers, Imaging. 2010; 41:135-41.

27. Vural M, Acar D, Toprak U, et al. The evaluation of the retrobulbar orbital fat tissue and optic nevre with strain ratio elastography. Med Ultrason. 2015;1:45-8.

28. Detorakis ET, Drakonaki EE, Ginis H, Karyotakis N, Pallikaris IG. Evaluation of iridociliary and lenticular elasticity using shear-wave elastography in rabbit eyes. Acta Medica.2014;57:9-14.

29. Hoyt K, Hah Z, Hazard C, Parker KJ. Experimental validation of acoustic radiation force induced shear wave interference patterns. Phys Med Biol. 2012;57:21-30.

30. Arda K, Ciledag N, Aktas E, Aribas BK, Köse K. Quantitative assessment of normal soft-tissue elasticity using shear-wave ultrasound elastography. AJR 2011; 197: 532-6.

31. Quigley HA. Glaucoma: macrocosm to microcosm the Friedenwald lecture. Invest Ophthalmol Vis Sci. 2005;46: 2662-70.

32. Pascolini D, Mariotti SP. Global estimates of visual impairment: 2010. Br J Ophthalmol.2012;96:614-8.

33. Pekel G, Agladıoglu K, Acer S, Yagcı R, Kasıkcı A. Evaluation of ocular and periocular elasticity after panretinal photocoagulation: an ultrasonic elastography study. Curr Eye Res. 2015;40:332-7.

34. Agladioglu K, Pekel G, Altintas Kasikci S, Yagci R, Kiroglu Y. An evaluation of ocular elasticity using real-time ultrasound elastography in primary open-angle glaucoma. Br J Radiol. 2016;89:20150429.

35. Unal O, Cay N, Yulek F, Taslipinar AG, Bozkurt S, Gumus M. Real-time ultrasound elastographic features of primary open angle glaucoma. Ultrasound Q. 2016;32:333-7.