Erciyes Med J 2017; 39(2): 48-53 • DOI: 10.5152/etd.2017.16099

ORIGINAL INVESTIGATION

Diastolic Sonoelastographic Strain Index for the Management of Thyroid Nodules

Hasan Yerli[1], Tuğbahan Yılmaz[2]

ABSTRACT

Objective: We aimed to establish whether employing the strain index method by applying manual compression synchronized with the diastolic period of the carotid artery by sonoelastography was useful to manage thyroid nodules.

Materials and Methods: Some 289 nodules belonging to 260 consecutive patients with thyroid nodules were prospectively included in this study. Both B-mode sonography and sonoelastography images were taken for each lesion. The strain indices (ratio of normal thyroid parenchyma to nodule strain) for the nodules were computed by making use of the same level and normal-appearing thyroid region as an internal reference. A comparison was made between the findings and histopathology or fine-needle aspiration biopsy. The diagnostic performances of both the strain index method and B-mode sonography were determined. Youden's index was utilized to compare the two methods.

Results: The mean strain index values were 1.52±2.43 (in the range 0.49-29.70) for 268 benign nodules and 4.94±3.96 (in the range 1.28-47.60) for 21 malignant nodules. Sensitivity and specificity were 88% and 80%, respectively, for B-mode sonography, whereas they were 75% and 93%, respectively, for the strain index method when the cutoff point used was 3.40. Youden's index was 0.68 for both B-mode sonography and the strain index method.

Conclusion: The strain index method using the external manual compression method synchronized with the diastolic period of the carotid artery by sonoelastography may be a diagnostic method that increases specificity in the management of thyroid nodules. Nevertheless, its diagnostic performance appears not superior to B-mode sonography.

Keywords: Sonoelastography, thyroid, ultrasonography, nodule, strain index

Cite this article as: Yerli H, Yılmaz T. Diastolic Sonoelastographic Strain Index for the Management of Thyroid Nodules. Erciyes Med J 2017; 39(2): 48-53.

[1]Department of Radiology, Baskent University, Zubeyde Hanim Practice and Research Center, İzmir, Turkey

[2]Department of General Surgery, Baskent University, Zubeyde Hanim Practice and Research Center, İzmir, Turkey

Submitted 24.09.2016

Accepted 7.11.2016

Correspondence Hasan Yerli, Department of Radiology, Baskent University, Zubeyde Hanim Practice and Research Center, İzmir, Turkey Phone: +90 232 241 10 00 e.mail: hasanyerli@yahoo.com

INTRODUCTION

B-mode sonography is a noninvasive, cost-effective, and valuable method to identify the location of a thyroid nodule and to evaluate the inner structure of the nodule. A significant disadvantage of B-mode sonography in differentiating between thyroid nodules is low specificity. The fine-needle aspiration biopsy (FNAB) is a simple, reliable, and generally safe diagnostic method for the evaluation of thyroid nodules, and a preoperative evaluation using the FNAB is helpful to differentiate between benign and malignant thyroid nodules (1-4). However, although minimal, the FNAB is an invasive procedure. The most common complications of the procedure are local pain and minor hematomas, whereas major hematomas appear rarely. Furthermore, in some patients, the anxiety likely to be caused by this procedure, owing to the use of a needle pushed forward toward the neck region, may even complicate its application. Moreover, it obviously increases the cost (1).

When compared with the malignant nodules of the thyroid, benign nodules are softer and more elastic, and the number of FNABs may be reduced by detecting benign nodules by means of sonoelastography. Sonoelastography that employs different scoring methods has commonly been investigated to differentiate between benign and malignant thyroid nodules (5-19). However, only a few manuscripts that present strain indices for the nodules of the thyroid gland have been published. So, as to compute the strain index during sonoelastographic examinations, the natural vascular pulsation of the carotid artery was used as the source of internal compression by some research groups, whereas the manual external compression method with a random-phase attempt was employed by some other researchers (17-23). The important internal out-of-plane movement that leads to an artifact in the manual compression method is the carotid systolic pulsation. Therefore, unlike other researchers, we applied the manual compression method in the diastole period as much as possible. So, it was aimed to provide more effective compression with the use of manual external compression method, to reduce internal deformation of the thyroid gland by minimizing the systolic pulsation effect of carotid and, as a result, to create more reliable and higher quality sonoelastography maps. Thereby, we used the manual compression method in the diastolic period to calculate the strain index of the thyroid nodules. We aimed to establish whether using the strain index method employing manual compression synchronized with the diastolic period of the carotid artery by sonoelastography was useful to manage thyroid nodules. We also compared the diagnostic performance of the strain index with that of B-mode sonography.

MATERIALS and METHODS

Patients

The present study was carried out as part of a prospective study approved by the Medicine and Health Sciences Research Board in the Faculty of Medicine at Başkent University (Project No. KA 10/51) and was supported by Başkent University. Ethics committee approval was received for this study from the ethics committee of the Faculty of Medicine at Başkent University. Informed consent was obtained from all patients.

Two hundred sixty consecutive patients (age range: 21-86 years; mean age: 55.2 years) with 289 solid thyroid nodules, for whom the FNAB or surgery was proposed on the basis of the criteria of the Society of Radiologists in Ultrasound, were evaluated between July 2010 and January 2015 (1). The largest diameter for the included nodules was 1 cm or greater. The nodules with a calcified shell or coarse calcification, the nodules located in the isthmus, the spongiform nodules, the nodules with a cystic component of >25%, and the nodules larger than 40 mm in diameter were excluded from the study (24). The nodules with an insufficient aspiration material for diagnosis on the FNAB and patients with high pulse rates and tachypneic patients were also excluded from the study.

The examinations of all patients were done by using both B-mode sonography and sonoelastography. All examinations were performed before surgery or the FNAB.

B-mode Sonography and Sonoelastography

All images were taken by means of the EUB-7000 and Preirus ultrasound system (Hitachi Medical Systems, Tokyo, Japan), including software with a combined autocorrelation method and a multihertz linear probe operating at 5-13 MHz. An experienced radiologist with 15 years of experience in the field of thyroid sonography performed the B-mode sonography and sonoelastography examinations at the same session. Both static and motion images of all cases were saved on the hard disk of the ultrasonography device.

On the B-mode sonographic examination, the images were evaluated in not only the transverse but also the longitudinal planes. The nodule shape, orientation, border, echogenicity, posterior acoustic shadowing and calcification properties were evaluated by B-mode sonography. While microcalcifications, marked hypoechogenicity, ill-defined margins, taller-than-wide shapes on the transverse view, and an increase in the dimension of a nodule were considered malignant nodule characteristics, hyperechogenicity, isoechogenicity, well-defined contours, and the halo sign were considered benign nodule characteristics (1-3, 25-28). Evaluations for B-mode sonography were applied at a different part by two investigators in consensus blinded to pathological diagnosis. In the sonoelastographical examinations, the transducer with a gel was placed onto the skin and sonoelastographic images with B-mode sonographic images were taken when the screen was in real time, thereby activating the sonoelastographic function. To compare both images

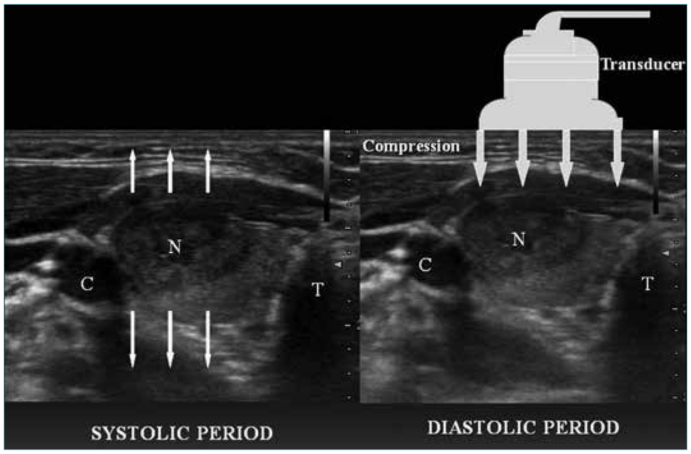

Figure 1. **B-mode sonographic images show the systolic (left image) and diastolic periods (right image) of the main carotid artery. Left: No compression was applied in the systolic period. Right: Manual external compression was applied in the diastolic period**

of the same scan plane, the sonoelastographic images were color-coded and superimposed on B-mode sonography on the left-hand side and the B-mode sonographic images on the right-hand side of the screen. The region of interest was predominantly between the strap muscles and the posterior part of the thyroid gland. The sonoelastographic maps were taken by applying suitable compression. When we lightly forced the probe in the diastolic cycle for this purpose, the pressure sign scale indicated either 3 or 4 in the EUB-7000 ultrasound system. The quality of tissue compression was shown by the sinusoidal graphic scale within the image in Preirus ultrasound system. The vertical amplitude of the transducer was in the range 1-2 mm. To operate the probe movement, free-hand management was preferred depending on the diastolic cycle of the carotid on the screen during the compressions (Figure 1). So as to attain perfect sonoelastographic images, the procedure was repeated until a stable map was reached. The sonoelastographic maps were taken according to a 256-color scale ranging from red to blue. Red represented the softest part of the nodule and showed the greatest strain; blue indicated the hardest part of the nodule that did not strain; and green showed intermediate elasticity.

The strain indices of the lesions were computed by considering the same level and normal thyroid gland part an internal reference (Figure 2, 3). For this purpose, region of interest (ROI) including the lesion was selected as A, whereas ROI covering the normal thyroid gland region was selected as B regarding with the nodule dimensions, so as to correctly find the difference in the elasticity of the nodule in comparison with the normal surrounding gland. The strain indices were automatically calculated as the B/A ratio. The most adequate image was selected from the images of the sonoelastography for strain index measurements. All measurements were done at a different period by two investigators in consensus blinded to pathological diagnosis. The strain indices of the lesions were compared with pathology. Histopathology and the FNAB were utilized as the reference standards. To ensure stability, follow-ups of the nodules with benign cytology were carried out for a minimum of 12 months.

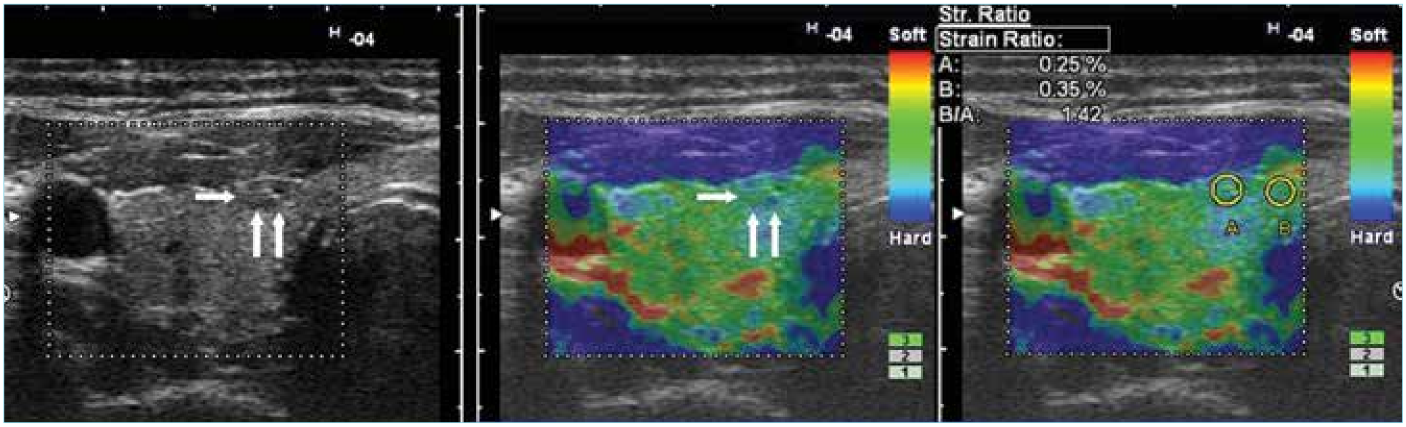

Figure 2. **A 42-year-old woman with a benign nodule. Left: The B-mode US image shows a hypoechoic nodule (arrows) including two microcalcifications. Middle: The sonoelastographic map shows a nodule (arrows) with green and some blue parts. Right: The strain index of the nodule was 1.42 with the same depth of the thyroid tissue as the reference**

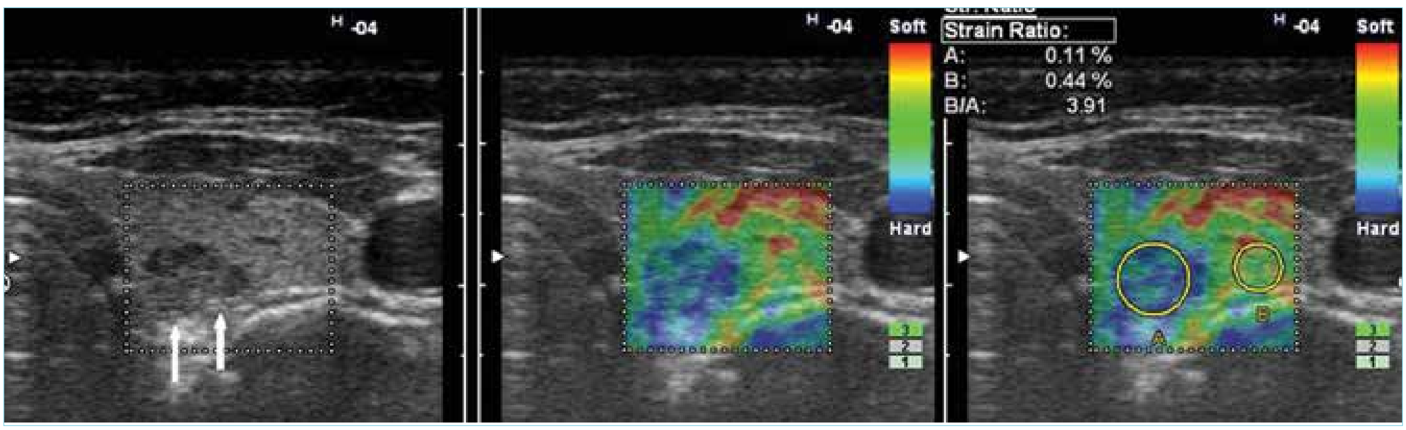

Figure 3. **A 52-year-old woman with a malignant nodule. Left: The B-mode US image shows a hypoechoic nodule (arrows). Middle: The sonoelastographic map shows a nodule with a predominantly blue color with some green parts. Right: The strain index of the nodule was 3.91 with the same depth of the thyroid tissue as the reference**

Statistical Analysis

Student's t-test was employed to assess the differences among the strain indices for benign and malignant thyroid nodules. Two-tailed $p<0.05$ was regarded as statistically significant. To propose optimum quantitative strain index criteria for differentiation between benign and malignant nodules, the best cutoff point to achieve the maximal mean of sensitivity and specificity was calculated. Accuracy, sensitivity, specificity, and positive and negative predictive values were calculated for B-mode US sonography and the strain index method. The diagnostic performances of both the strain index method and B-mode sonography were compared by the help of Youden's index (Y=sensitivity+specificity-1). All statistical analyses were conducted with the Statistical Packages for the Social Sciences (SPSS) version 15.0 (SPSS Inc.; Chicago, IL, USA).

RESULTS

Nodules

The dimensions of all 289 lesions were in the range 6-30 mm (mean: 12.4 mm) along the short axis and in the range 10-36 mm (mean: 18.4 mm) along the long axis. Of 289 nodules, 220 (76%) were solid and 69 (24%) were mostly solid (nodules with a solid component of >25%). One hundred ninety-three nodules were present in the right lobe and 96 were present in the left lobe.

B-mode Sonography and Sonoelastography Imaging Findings

B-mode sonography was successfully carried out in all cases. The B-mode sonography features of thyroid nodules are shown in Table 1. Sonoelastography was technically successful in 270 of 289 nodules (95%). Sonoelastography failed in nine deeply located nodules in six patients and could not be performed in two nodules of two patients with cervical osteoarthritis and in two nodules of two patients with a short neck feature. Discrimination of the diastolic cycle of the carotid on the screen during the compressions was impossible in six nodules of five patients.

The mean strain index values were 1.52±2.43 (in the range 0.49-29.70) for 268 benign lesions and 4.94±3.96 (in the range 1.28-47.60) for 21 malignant lesions ($p<0.05$). When the best cutoff point for the strain index was considered as 3.40, 20 false-positive lesions were present; moreover, seven false-negative lesions were detected by employing the strain index method. Sixty-seven false-positive and four false-negative lesions were found by B-mode sonography. The performance values of B-mode sonography and the strain index to differentiate between benign and malignant nodules are presented in Table 2. Youden's index was 0.68 for both B-mode sonography and the strain index method.

Table 1. The B-mode sonography features of 289 thyroid nodules

Method	Benign (n=268)	Malignant (n=21)
B-mode sonography		
Echogenicity		
Hyperechoic	16	0
Isoechoic	69	2
Hypoechoic	111	12
Markedly hypoechoic	31	4
Mixed	41	3
Structure		
Solid	207	19
Mixed	61	2
Contour		
Well-defined	226	5
Microlobulated	18	4
Ill-defined	24	12
Microcalcification		
Present	56	7
Absent	212	14
Taller-than-wide sign		
Present	32	6
Absent	236	15
Halo sign		
Present	28	2
Absent	240	19

Table 2. Diagnostic performance of B-mode sonography and the strain index in 289 thyroid nodules

Method	Accuracy (%)	Sensitivity (%)	Specificity (%)	NPV (%)	PPV (%)
B-mode sonography	90	88	80	97	53
Sonoelastography					
Strain index*	93	75	93	97	57

NPV: negative predictive value; PPV: positive predictive value
*Ratios for the strain index on the basis of the cases in which technical success was achieved

DISCUSSION

The technique of B-mode sonography is a widely used primary method of examining the thyroid nodules. It is an excellent method for differentiating completely cystic nodules, which are almost entirely benign, from solid nodules. Still, this method remains insufficient for differentiating between benign and malignant solid and partly solid nodules (1). The sonographic criteria defined by researchers for malignant nodules, such as marked hypoechogenicity, taller-than-wide morphology, microcalcifications, and ill-defined contours, are also observed in benign nodules (1, 25-28). Wienke et al. (3) discovered that at least one of the findings prevalent in malignant nodules was observed in 69% of the benign nodules out of a series of 68 benign nodules. We found this rate as 25% in our study with 268 benign nodules.

The prevalence of thyroid nodules reaches 50% in B-mode US and autopsy studies. The vast majority of the nodules found in the population (around 95%) are benign (1-2). The absence of an accepted definite standard regarding to which nodule the FNAB will be applied, which results in an increase in cost. For instance, the American Thyroid Association recommends the FNAB for all hypoechoic solid nodules without microcalcification that are 10 mm or greater (28). According to the Society of Radiologists in Ultrasound, if microcalcification is present, it is recommended to apply the FNAB to those nodules the largest diameter of which is 1 cm or greater (1). Based on these guidelines, it is observed that the rate of benign nodules is still high in the series to which the FNAB was applied.

The thyroid gland is well located for sonoelastography evaluation, and it can usually be effectively compressed by means of a superficial probe. Numerous original reports that applied the compression method have shown that sonoelastography using the scoring system can be helpful in differentiating between benign and malignant thyroid nodules (5-11, 13-16). We also published a manuscript with a smaller number of participants as a technical note (9). In our previous study, we used a scoring system to define a nodule as malignant or benign (9). In this study, we slightly modified the scoring methods of Tsukuba and an Italian research group, and we showed that the five-point scoring technique using the external manual compression technique synchronized with the diastolic cycle of the carotid by sonoelastography can be useful to manage thyroid nodules. In our previous scoring study, we determined that sensitivity and specificity were 83% and 89%, respectively, when a cutoff point between scores three and four was used. However, when using the subjective five-point scoring method, there may be inconsistencies between the scorings of the observers. Thus, scientists have investigated more objective methods of measurement.

Several manuscripts that present strain indices for the nodules of the thyroid so as to discover the contribution to nodule characterization have been published (20-23, 29, 30). Bae et al. (17) used carotid artery systolic pulsation as the internal compression source and found the strain index that was calculated as the ratio of strain near the carotid artery to that of a low stiff part inside a thyroid nodule. Evaluation of thyroid nodules by making use of the thyroid stiffness index measurement they define in their study is a labor-intensive method that is applied in non-real time. Additionally, the nodules on the isthmic region cannot be compressed with this method, for they are localized in the anterior part of the trachea. In addition, in an evaluation with this method, one may fail to attain optimum compression if a calcified plaque is present in the carotid artery. In our study, we at least observed that the pressure scale did not reach 3 when an evaluation was made only with systolic pulsation in some nodules. That is to say, in some lobe nodules, adequate compression cannot be provided only by carotid artery systolic pulsation, nor can any successful elastogram image be obtained. Dighe et al. (18) stated that, in their study, the elastographic examination failed in 1 of 62 thyroid nodules. Nevertheless, the absence of a pressure scale indicating whether the applied compression was adequate in the studies by Dighe et al. (18) and Bae et al. (17) with this method encourages one to think that there was a possibility of a failure to provide adequate compression in some cases they included in their studies. Lyshchik et al. (31) computed the strain indices of nodules and found that a strain index value greater than 4 was a helpful parameter in the diagnosis of malignant nodules. However, Lyshchik et al. (31) pointed out that when compared with real-time elastography, off-line evaluation of strain maps was a considerably time-consuming method that should be developed. The diagnostic efficiency of the strain index method is controversial, and it is reported in one recent study that there is a need for prospective randomized studies to determine the value of this method (20).

A small amount of compression by the natural vascular pulsation of the carotid may not provide adequate compression on some nodules of the thyroid gland. Besides, in an evaluation with the natural vascular pulsation method, one may fail to achieve optimum compression if a calcified plaque is present in the carotid artery. However, the manual external compression method is much more effective on nodules than the method by using natural vascular pulsation. Unlike other researchers, we employed manual compression in the diastolic cycle to prevent the possible deformation on the thyroid gland and thereby for more reliable and effective compression and calculating the strain index of the thyroid nodules (Figure 1). There is a pressure scale simultaneously displaying the appropriateness of the manipulation as upward and downward movements on the US screen. In our study, we measured the strain index by taking the normal-appearing thyroid tissue, which was at the same level as the nodule, as a reference after the sonoelastographic maps had been obtained. By employing that method, we determined 93% specificity and 75% sensitivity. In other studies carried out with manual compression and strain index methods regardless of the systolic or diastolic period, specificity values varied between 68% and 96% and sensitivity values varied between 91% and 99% (20-23, 29, 30). Of these studies, Cakir et al. (22) achieved the highest specificity and sensitivity values (96% and 99%, respectively). However, the patients included in their studies formed a selected group that underwent surgery. The results of other researchers mostly resemble the results of our study. Therefore, one can think that there may not be any difference in the evaluation of elasticity between manual compression applied in the diastolic period and randomly applied manual compression. Thus, there is a need for an advanced study to compare the elasticity values to be obtained by manual compression in the diastolic period and randomly applied manual compression.

The method we defined is inappropriate for some patients in whom the discrimination of the diastolic time of the carotid artery on the screen during manual compressions was impossible. Six nodules were not evaluated for this reason. A general disadvantage of sonoelastography is that the small tumor focuses in the nodule may be missed because a decision is taken for the whole nodule. The other limitation of sonoelastography is that the nodules with a calcified wall or macrocalcification are unsuitable for sonoelastographic examination, for coarse calcifications cause stiffness in the nodule and can have a false-positive effect (24). Therefore, we excluded the nodules with a calcified shell or coarse calcification. In our study, sonoelastography was technically successful in 270 of 289 nodules (95%). Sonoelastography failed in nine deeply located nodules in six patients. It could not be performed in two nodules of two patients with cervical osteoarthritis and in two nodules of two patients with a short neck feature. These limitations were not previously defined in the literature. In addition, it may be rather hard to find a correct strain index value in tachycardiac or tachypneic patients through this method. Besides, evaluations of the nodules placed in the isthmus of the gland and evaluations of the nodules with a common cystic part are also limitations of sonoelastography (24). For the above-mentioned reasons, sonoelastography was technically successful in 270 of 289 nodules (95%) in our patient population, although B-mode sonography was successfully applied in all cases.

The lack of an interobserver compatibility study is the main limitation of our study. Another limitation is the subjectivity of the discrimination of the diastolic part of the carotid on the screen during manual compressions. Thirdly, we merely made a comparison between the diagnostic performances of the strain index and B-mode sonography but did not evaluate the performance of the scoring method.

CONCLUSION

The strain index method using the manual compression method synchronized with the diastolic time of the carotid by sonoelastography may be a diagnostic method that increases specificity in managing thyroid nodules. However, its diagnostic performance appears to be not superior to B-mode sonography, and the value of the technique is reduced by a wide range of overlap of strain index values for benign and malignant nodules and by the other disadvantages that we defined.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of the faculty of medicine at Baskent University.

Informed Consent: Written informed consent was obtained from patient who participated in this study.

Peer-review: Externally peer-reviewed.

Author Contributions: Conceived and designed the experiments or case: HY., TY. Performed the experiments or case: HY., TY. Analyzed the data: HY., TY. Wrote the paper: HY., TY. All authors have read and approved the final manuscript.

Acknowledgements: The authors thank to the Baskent University for contributing some facilities to complete this work.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

REFERENCES

1. Frates MC, Benson CB, Charboneau JW, Cibas ES, Clark OH, Coleman BG, et al. Management of thyroid nodules detected at US: Society of Radiologists in Ultrasound consensus conference statement. Radiology 2005; 237(3): 794-800. [CrossRef]
2. Brander A, Viikinkoski P, Nickels J, Kivisaari L. Thyroid gland: US screening in a random adult population. Radiology 1991; 181(3): 683-7. [CrossRef]
3. Wienke JR, Chong WK, Fielding JR, Zou KH, Mittelstaedt CA. Sonographic features of benign thyroid nodules: interobserver reliability and overlap with malignancy. J Ultrasound Med 2003; 22(10): 1027-31. [CrossRef]
4. Suen KC. Fine-needle aspiration biopsy of the thyroid. Can Med Assoc J 2002; 167: 491-5.
5. Asteria C, Giovanardi A, Pizzocaro A, Cozzaglio L, Morabito A, Somalvico F, et al. US-elastography in the differential diagnosis of benign and malignant thyroid nodules. Thyroid 2008; 18(5): 523-31. [CrossRef]
6. Tranquart F, Bleuzen A, Pierre-Renoult P, Chabrolle C, Sam Giao M, Lecomte P. Elastosonography of thyroid lesions. J Radiol 2008; 89(1): 35-9 [CrossRef]
7. Rago T, Scutari M, Santini F, Loiacono V, Piaggi P, Di Coscio G, et al. Real-time elastosonography: useful tool for refining the presurgical diagnosis in thyroid nodules with indeterminate or nondiagnostic cytology. J Clin Endocrinol Metab 2010; 95(12): 5274-80. [CrossRef]
8. Rubaltelli L, Corradin S, Dorigo A, Stabilito M, Tregnaghi A, Borsato S, et al. Differential diagnosis of benign and malignant thyroid nodules at elastosonography. Ultraschall Med 2009; 30(2): 175-9. [CrossRef]
9. Yerli H, Yilmaz T, Oztop I. Clinical importance of diastolic sonoelastographic scoring in the management of thyroid nodules. AJNR Am J Neuroradiol 2013; 34(3): E27-30. [CrossRef]
10. Ragazzoni F, Deandrea M, Mormile A, Ramunni MJ, Garino F, Magliona G, et al. High diagnostic accuracy and interobserver reliability of real-time elastography in the evaluation of thyroid nodules. Ultrasound Med Biol 2012; 38(7): 1154-62. [CrossRef]
11. Friedrich-Rust M, Sperber A, Holzer L, Diener J, Grünwald F, Badenhoop K, et al. Real-time elastography and contrast-enhanced ultrasound for the assessment of thyroid nodules. Exp Clin Endocrinol Diabetes 2010; 118(9): 602-09. [CrossRef]
12. Sun J, Cai J, Wang X. Real-time ultrasound elastography for differentiation of benign and malignant thyroid nodules:a meta-analysis. J Ultrasound Med 2014; 33(3): 495-502. [CrossRef]
13. Trimboli P, Guglielmi R, Monti S, Misischi I, Graziano F, Nasrollah N, et al. Ultrasound sensitivity for thyroid malignancy is increased by real-time elastography: a prospective multicenter study. J Clin Endocrinol Metab 2012; 97(12): 4524-30. [CrossRef]
14. Merino S, Arrazola J, Cardenas A, Mendoza M, De Miguel P, Fernández C, et al. Utility and interobserver agreement of ultrasound elastography in the detection of malignant thyroid nodules in clinical care. AJNR Am J Neuroradiol 2011; 32(11): 2142-48. [CrossRef]
15. Cappelli C, Pirola I, Gandossi E, Agosti B, Cimino E, Casella C, et al. Real-time elastography: a useful tool for predicting malignancy in thyroid nodules with nondiagnostic cytologic findings. J Ultrasound Med 2012; 31(11): 1777-82. [CrossRef]
16. Azizi G, Keller J, Lewis M, Puett D, Rivenbark K, Malchoff C. Performance of elastography for the evaluation of thyroid nodules: a prospective study. Thyroid 2013; 23(6): 734-40. [CrossRef]
17. Bae U, Dighe M, Dubinsky T, Minoshima S, Shamdasani V, Kim Y. Ultrasound thyroid elastography using carotid artery pulsation: preliminary study. J Ultrasound Med 2007; 26(6): 797-805. [CrossRef]
18. Dighe M, Kim J, Luo S, Kim Y. Utility of the ultrasound elastographic systolic thyroid stiffness index in reducing fine-needle aspirations. J Ultrasound Med 2010; 29(4): 565-74. [CrossRef]
19. Choi WJ, Park JS, Koo HR, Kim SY, Chung MS, Tae K. Ultrasound elastography using carotid artery pulsation in the differential diagnosis of sonographically indeterminate thyroid nodules. AJR Am J Roentgenol 2015; 204(2): 396-401. [CrossRef]
20. Guazzaroni M, Spinelli A, Coco I, Del Giudice C, Girardi V, Simonetti G. Value of strain-ratio on thyroid real-time sonoelastography. Radiol Med 2014; 119(3): 149-55. [CrossRef]
21. Xing P, Wu L, Zhang C, Li S, Liu C, Wu C. Differentiation of benign from malignant thyroid lesions: calculation of the strain ratio on thyroid sonoelastography. J Ultrasound Med 2011; 30(5): 663-9. [CrossRef]
22. Cakir B, Ersoy R, Cuhaci FN, Aydin C, Polat B, Kılıc M, et al. Elastosonographic strain index in thyroid nodules with atypia of undetermined significance. J Endocrinol Invest 2014; 37(2): 127-33. [CrossRef]
23. Aydin R, Elmali M, Polat AV, Danaci M, Akpolat I. Comparison of muscle-to-nodule and parenchyma-to-nodule strain ratios in the differentiation of benign and malignant thyroid nodules: which one should we use? Eur J Radiol 2014; 83(3): e131-6. [CrossRef]
24. Szczepanek-Parulska E, Woliński K, Stangierski A, Gurgul E, Ruchała M. Biochemical and ultrasonographic parameters influencing thyroid nodules elasticity. Endocrine 2014; 47(2): 519-27. [CrossRef]
25. Kim EK, Park CS, Chung WY, Oh KK, Kim DI, Lee JT, et al. New sonographic criteria for recommending fine-needle aspiration biopsy of nonpalpaple solid nodules of the thyroid. AJR 2002; 178(3): 687-91. [CrossRef]
26. Kwak JY, Han KH, Yoon JH, Moon HJ, Son EJ, Park SH. Thyroid imaging reporting and data system for US features of nodules: a step in establishing better stratification of cancer risk. Radiology 2011; 260(3): 892-9. [CrossRef]
27. Moon HJ, Sung JM, Kim EY, Yoon JH, Youk JH, Kwak JY. Diagnostic performance of gray-scale US and elastography in solid thyroid nodules. Radiology 2012; 262(3): 1002-13. [CrossRef]
28. Haugen BR, Alexander EK, Bible KC, Doherty GM, Mandel SJ, Nikiforov YE, et al. 2015 American Thyroid Association Management Guidelines for Adult Patients with Thyroid Nodules and Differentiated Thyroid Cancer. Thyroid 2016; 26(1): 1-133. [CrossRef]
29. Chong Y, Shin JH, Ko ES, Han BK. Ultrasonographic elastography of thyroid nodules: Is adding strain ratio to colour mapping better? Clin Radiol 2013; 68(12): 1241-6. [CrossRef]
30. Magri F, Chytiris S, Capelli V. Comparison of elastographic strain index and thyroid fine-needle aspiration cytology in 631 thyroid nodules. J Clin Endocrinol Metab 2013; 98(12): 4790-7. [CrossRef]
31. Lyshchik A, Higashi T, Asato R, Tanaka S, Ito J, Mai JJ, et al. Thyroid gland tumor diagnosis at US elastography. Radiology 2005; 237(1): 202-11. [CrossRef]