Original Article

Diagnostic Accuracy of Strain Elastography Ultrasound in Differentiation of Benign and Malignant Breast Lesions with Histopathological Correlation

Tarana Yasmin[1], Mashah Binte Amin[2], Samar Chandra Sarkar[3], Kaniza Kabir[4], Samanta Faria[5]

Received: 17 February 2021 Accepted: 30 March 2021
doi: https://doi.org/10.3329/jemc.v11i2.65192

Abstract

Background: *Palpable breast masses are common and usually benign, but efficient evaluation and prompt diagnosis are necessary to rule out malignancy. High frequency high resolution ultrasonogram helps in its evaluation. With major advances in ultrasonographic technology, ultrasound elastography can improve differentiation between benign and malignant breast lumps. Knowledge of the specific ultrasonogram elastographic characteristics of breast lumps can be offered as a viable alteration to biopsy and imperative for optimal patient management.* ***Objective***: *To determine the validity of ultrasound elastography strain ratio in differentiation of benign and malignant breast lesions by detecting the sensitivity, specificity, positive predictive value, negative predictive value and accuracy of ultrasound elastography in diagnosis of benign and malignant breast lesions.* ***Materials and Methods***: *This cross-sectional analytical study was done in the department of Radiology & Imaging of Enam Medical College & Hospital during July 2016 to June 2017. A total number of 104 patients were included in this study. Data on clinical presentation, ultrasonographic, sonoelastographic findings including histopathological report were collected and documented in structured forms. Analysis was done using SPSS 20.0 version.* ***Results***: *The study was done on 104 women of 19−60 years of age with the mean age of 34.65±5.5 years. Out of sonographically diagnosed 80 benign lesions also having lower elastography strain ratio (2.73±0.87), 75 (94%) were proved benign histopathalogically. With these criteria for diagnosis of benign lesion, sensitivity was 94.9%, specificity 80%, positive predictive value 93.7%, negative predictive value 83.3% and accuracy 91.3%. Sonographically 24 lesions were diagnosed as malignant also having higher elastography strain ratio (8.1±1.38), out of these 20 (83%) cases were proven malignant histopathalogically with sensitivity of 80%, specificity 94.9%, positive predictive value 83.3%, negative predictive value 93.7% and accuracy 91.3%.* ***Conclusion:*** *Ultrasound elastographic findings of benign and malignant breast lesions correlated well in most of the cases with the histopathological results. So combined use of ultrasound and ultrasound elastography provide better diagnostic yield and thus allowed sparing of cumbersome invasive diagnostic procedures.*

Key words: *Ultrasound; Elastography; Benign; Malignant; Breast lesion*

J Enam Med Col 2021; 11(2): 99−107

1. Associate Professor, Department of Radiology, Enam Medical College & Hospital, Savar, Dhaka
2. Associate Professor, Department of Radiology, Enam Medical College & Hospital, Savar, Dhaka
3. Professor, Department of Radiology, Enam Medical College & Hospital, Savar, Dhaka
4. Associate Professor, Department of Radiology, Enam Medical College & Hospital, Savar, Dhaka
5. Assistant Professor, Department of Radiology, Enam Medical College & Hospital, Savar, Dhaka
Correspondence *Tarana Yasmin, Email: tarana843@gmail.com*

Introduction

The most common breast lump by age is fibroadenoma in young women, cyst or fibrocystic changes in middle-aged women and cancer in older women.[1] Breast cancer is one of the most common cancer in women, accounting for 21% of cancer diagnosed[2] and causes high morbidity and second most common cause of cancer-related mortality.[3] Recent research on service screening programs suggests that participation in modern, organized service screening may reduce the risk of breast cancer by 40% or more.[4] Early and sensitive diagnosis represents a better prognosis. But noninvasive diagnosis of breast cancer remains a major clinical problem and a large number of biopsies performed for benign breast abnormalities.

There are many imaging modalities for detecting breast lump. But mammography and sonography are currently the most sensitive modalities. For early detection of breast cancer, mammography is currently the most widely used screening modality, but it has a low negative predictive value. In patient with palpable abnormalities of the breast, false-negative rate for mammography has been reported to be 18%.[5] Therefore, many masses referred for breast biopsy on the basis of mammography findings are actually benign.

In the absence of a lesion, biopsy is still performed for clinically questionable palpable abnormalities because of the reported false-negative rate of mammography. As clinical breast examination is not absolute, many surgeons liberally performed biopsies. But the biopsie results for cancer is only 10% to 30%.[6] This means that 70% to 90% of breast biopsies are performed for benign diseases which induce unnecessary patient discomfort and anxiety in addition to increase cost to the patient. Moreover, increase in breast tissue density reduces the diagnostic accuracy of breast cancer in mammography, especially in younger females.[7] Thus, as the proportion of glandular breast tissue rises, other imaging methods are required.[8] Gray-scale ultrasonography is a valuable adjunct to mammography and other breast imaging methods, affording highly sensitive assessment of breast masses.[9–11] However, ultrasonography is strongly subjective and poorly specific.[12–14] Therefore, there is a great need for development of additional reliable, noninvasive, cost-effective method helping to differentiate benign from malignant breast lesions, thus reducing the number of unnecessary interventional diagnostic procedures.

Recently, sonoelastography which estimates tissue strain has been used as an adjunct to the conventional ultrasound B-mode examination for diagnosis of breast lesions. It improves the diagnostic reliability of sonography, increases specificity and allows better differentiation between benign and malignant focal lesions. Therefore, the number of false-positive findings in breast lesion diagnosis has been reduced by using ultrasound elastography.[15–18]

Elastography is the technique of imaging the hardness of soft tissue. Strain images display the relative stiffness of lesions compared with the stiffness of surrounding tissue. Stiffer areas deform less easily than do their surroundings whereas softer areas deform more easily than do their surroundings. Malignant masses are typically less compressible and benign masses deform easily.[19] The interpretation criteria in elastography consist of the qualitative parameter elasticity score (ES) and the quantitative parameter strain ratio (SR). Calculation of the SR value is based on determining the average strain measured in a lesion and comparing it to the average strain of a similar area of fatty tissue in the adjacent breast tissue. The strain ratio (SR) reflects the relative stiffness of the lesion. Probability of malignancy increases as the strain ratio (SR) value increases.[20] Tissue elasticity imaging is performed with a conventional ultrasound probe and does not require additional equipment.

The current prospective study aimed to evaluate the diagnostic yield of ultrasound elastography using strain ratio (SR) for differentiating breast lesions as benign or malignant in comparison with histopathological examination.

Materials and Methods

This cross-sectional analytical study was carried in the department of radiology and imaging department of Enam Medical College & Hospital during July 2016 to June 2017. This study was carried out on purposively selected 104 patients ranging from

19−60 years having breast lump with the mean age of 34.65±5.5 years.

After taking consent from all, patients underwent radiological workup that included B-mode ultrasonography and ultrasound elastography. Using B-mode imaging, morphological characteristics of lesions were determined.

All elasticity images were obtained with a system that consisted of a digital US scanner. The US probe was a 7.5-MHz linear electronic probe. The top of the region of interest (ROI) included subcutaneous fat and the bottom included the pectoral muscles and lateral borders were set >5 mm from the lesion's boundary. The strain index, defined as the fat to mass strain ratio (SR) that indicated mass stiffness, was evaluated. One ROI was placed in the focal lesion and the reference ROI was placed in the surrounding normal tissue, preferably in the same depth as the lesion. The strain ratio (SR) was automatically calculated by the elastography software. The likelihood of malignancy was established based on Ultrasound Elastographic criteria (higher strain ratio). Finally ultrasound elastographic findings that is the strain ratio of breast lesions were correlated with histopathological reports.

The results were statistically analyzed using SPSS software statistical computer package version 20.0 for quantitative data. For the validity of the study outcome sensitivity, specificity, positive and negative predictive values and accuracy were calculated out after confirmation of the diagnosis histopathalogically.

Results

A total 104 cases were selected who were clinically suspected of having breast lump. Mean age of the patients was 34.65±5.5 years ranging from 19 to 60 years.

All the cases complained of lump in the breast, 67% cases complained for mastalgia, 12% presented with nipple discharge, 14% cases with nipple retraction, 11% presented with skin changes, and 24% presented with palpable axillary lymph node (Table I).

Table I: Distribution of respondents according to clinical features (n= 104)

Clinical features	Number	Percentage
Lump	104	100
Mastalgia	70	67
Nipple discharge	13	12
Nipple retraction	15	14
Skin change	12	11
Palpable lymph node	25	24

Some subjects had more than one complaints.

Sonographically, benign lesions were diagnosed in 80 cases. Common sonological criterias were well-defined margin in 65 (81%) cases, 50 (63%) cases were hypoechoic in echotexture. Oval and round shape was present in 66 (83%) cases and homogeneous internal echo was seen in 60 (75%) cases. Sixty seven (84%) cases showed bilateral edge shadow and 70 (88%) cases showed compressibility. And 65 (81%) cases showed no architectural disruption (Table II and Fig 1).

Sonographically malignant masses were diagnosed in 24 cases having following common criteria – ill-defined margin in 20 (83%) cases, irregular shape in 19 (79%) cases. Twenty one (88%) cases had more hypo to anechoic echogenicity. Heterogeneous internal echoes were seen in 18 (75%) cases. Bilateral edge shadow and compressibility were seen only in 22 (92%) cases. Twenty three (96%) cases showed architectural disruption (Table III and Fig 2).

Eighty cases diagnosed as benign masses with morphological sonographic criteria showed lower strain ratio (mean SR 2.73±0.87) in ultrasound elastography whereas sonographically diagnosed 24 cases of malignant masses showed higher strain ratio (mean SR 8.1±1.38). Strain ratio of malignant lesions was significantly ($p<0.0001$) higher than that of benign lesions when cut-off value 4.4 was used (Table IV and Fig 3 and 4).

Using strain ratio < 4.4, 80 cases were diagnosed as benign masses after histopathological correlation 75 cases were found as benign and 5 cases were found as malignant. Using strain ratio ≥ 4.4, 24 cases were diagnosed as malignant masses after histopathological correlation 20 cases were found as malignant and 4 cases were found as benign (Table V).

Table II: Distribution of respondents according to morphological sonographic features of benign masses (n= 80)

Morphological sonographic criteria	Number	Percentage
Margin		
Well defined	65	81
Ill defined	15	19
Echogenicity		
Hypoechoic	50	63
Isoechoic	5	6
Hyperechoic	20	25
More hypoechoic to anechoic	5	6
Shape		
Oval and round	66	83
Irregular	14	17
Internal echoes		
Homogeneous	60	75
Heterogeneous	20	25
Architectural disruption		
Present	15	19
Absent	65	81
Bilateral edge shadow		
Present	67	84
Absent	13	16
Compressibility		
Absent	10	12
Present	70	88

Table III: Distribution of respondents according to morphological sonographic features of malignant masses (n=24)

Morphological sonographic criteria	Number	Percentage
Margin		
Well-defined	4	17
Ill-defined	20	83
Echogenicity		
Hypoechoic	3	12
Morehypoechoic to anechoic	21	88
Shape		
Oval and round	5	21
Irregular	19	79
Internal echoes		
Heterogeneous	18	75
Homogeneous	6	25
Bilateral edge shadow		
Absent	2	8
Present	22	92
Architectural disruption		
Absent	1	4
Present	23	96
Compressibility		
Present	2	8
Absent	22	92

Table IV: Strain elastographic ultrasound findings (strain ratio)

Types of lesions	Mean SR	p value
Sonographically benign lesions (n=80)	2.73±0.87	<0.0001
Sonographically malignant lesions (n=24)	8.1±1.38	

Table V: Correlation of strain ratio (SR) of breast lesions with histopathological findings

Strain ratio	Histopathologically positive	Histopathologically negative
< 4.4 (benign) (n=80)	75	5
≥ 4.4 (malignant) (n=24)	20	4

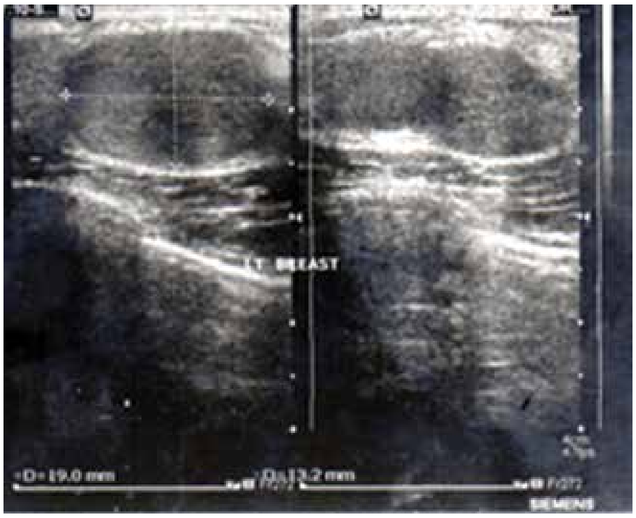

Fig 1. USG of benign breast lesion

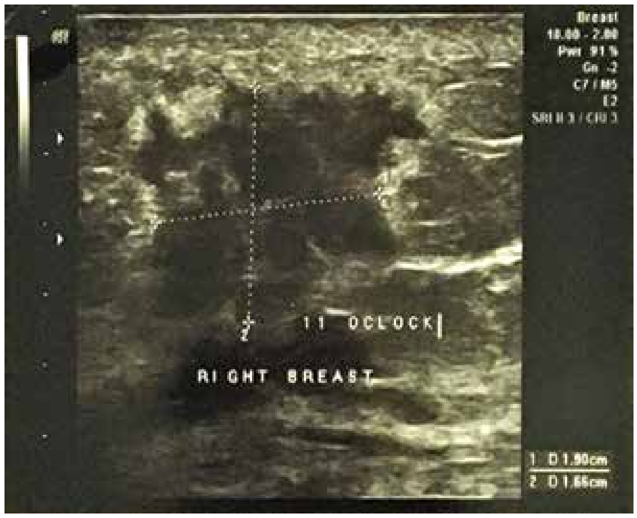

Fig 2. USG of malignant breast lesion

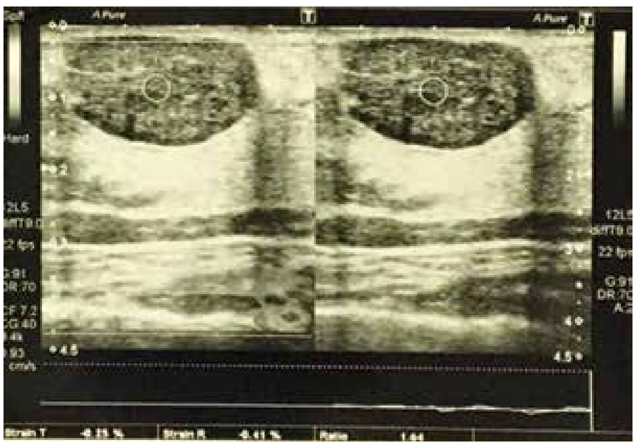

Fig 3. USG of benign breast lesion

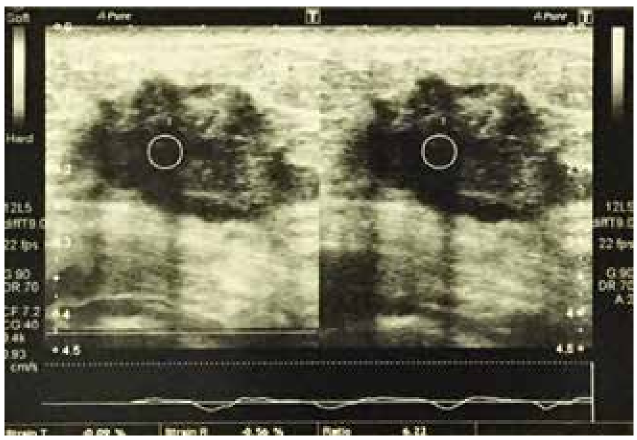

Fig 4. USG of malignant breast lesion

The sonoelastographic criteria used for diagnosing benign masses was lower strain ratio (mean SR 2.73±0.87). After histopathological correlation with this criteria it was found to be true positive in 75 cases, true negative in 20 cases, false positive in 5 cases and false negative in 4 cases giving a sensitivity of 94.9%, specificity of 80%, positive predictive value of 93.7% and negative predictive value of 83.3%. Overall diagnostic accuracy of the test was 91.3%.

The sonoelastographic criteria used for diagnosing malignant masses was higher strain ratio (mean SR 8.1±1.38). After histopathological correlation with this criteria it was found to be true positive in 20 cases, true negative in 75 cases, false positive in 4 cases and false negative in 5 cases giving a sensitivity of 80%, specificity of 94.9%, positive predictive value of 83.3% and negative predictive value of 93.7%. Overall diagnostic accuracy of the test was 91.3%

Discussion

Breast masses have become common in women. Although breast imaging is most routinely thought of as a screening and diagnostic tool to detect and manage breast cancer, benign breast lesions are vastly more common than malignant lesions and often require accurate diagnosis to rule out cancer. Breast sonography has become an indispensable tool in the evaluation of breast lesions. However, ultrasonography is strongly subjective and there is an overlap between the sonographic appearances of benign and malignant lesions. So for diagnosis of suspicious breast lesions, biopsies are done in a large proportion of benign lesions. Therefore, a noninvasive and reliable method identifying low-risk lesions, and reducing unnecessary interventional diagnostic procedures, would be valuable. Ultrasound elastography with measuring the mass/fat ratio (strain ratio) can be used to differentiate benign from malignant solid breast lesions.

The current study was performed to explore the accuracy of strain ultrasound elastography using strain ratio in differentiation of benign and malignant breast lesions with histopathological correlation. One hundred four women with breast lumps attending the department of Radiology & Imaging, EMCH were enrolled in the study. Strain ratio of breast lesions were measured with Ultrasound elastography and were correlated with histopathological findings.

In our study sonological criteria for diagnosis of benign and malignant lesions were also comparable to those of other studies. Rahbar et al[21] found that the features most likely to predict a benign diagnosis in solid masses were round or oval shape, had a circumscribed margin, and had a width-to-anteroposterior ratio greater than 1.4. These results were also in conformity with the results obtained by Singh et al[22], Stavros et al[11] and other studies.[23,24] The typical features of malignancy include irregular shape, irregular contour, hypoechogenicity, a surrounding echogenic rim and posterior acoustic shadowing.[11,25] According to Pande et al[26] shape, margins, vascularity, surrounding tissue character, sound transmission through the lump are more significant in the diagnosis of benign and malignant lumps.

We have shown that the mass/fat ratio using ultrasound elastography (strain ratio) can be used to differentiate benign from malignant solid breast lesions and the most useful and reproducible measure was the mass/fat elasticity ratio. Breast fat tissue shows minimal elastographic variability, and the elasticity values are very low, supporting the use of fat tissue stiffness as a comparator.[27,28] The mass/fat elasticity ratio (strain ratio) is not influenced by compression because breast fat tissue and the lesion are subjected to the same pressure.

In this study the quantitative ultrasound elastographic criteria strain ratio (SR) was used for differentiating benign and malignant lesions and the study showed strain ratio of malignant lesions was significantly ($p<0.0001$) higher than that of benign lesions when cut-off value was 4.4. In the current study benign masses had lower strain ratio (mean SR 2.73±0.87). After histopathological correlation with this criteria it was found to be true positive in 75 cases, true negative in 20 cases, false positive in five cases and false negative in four cases giving a sensitivity of 94.9%, specificity 80%, positive predictive value 93.7% and negative predictive value 83.3%. Overall diagnostic accuracy of the test was 91.3%. The sonoelastographic criteria used for diagnosing malignant masses was higher strain ratio (mean SR 8.1±1.38). After histopathological correlation with these criteria it was found to be true positive in 20 cases, true negative in 75 cases, false positive in 04 cases and false negative in 05 cases giving a sensitivity of 80%, specificity of 94.9%, positive predictive value of 83.3% and negative predictive value of 93.7%. Overall diagnostic accuracy of the test was 91.3%.

In support of the obtained results Mansour &

Omar[29] found ultrasound elastography, using both qualitative and quantitative methods, can improve the specificity and accuracy in the diagnosis of breast lesions. Fischer et al[30] documented that strain ratio calculation contributes to the sonoelastography with high sensitivity and allows significant differentiation between benign and malignant breast lesions.

Alhabshi et al.[31] found the sensitivity and specificity of combined ultrasound elastography and conventional US were significantly higher and the assessment with strain ratio in UE were the most useful parameters in differentiating between benign and malignant breast lesions.

Zhang et al[32] evaluated ultrasound elastography in differentiating breast tumors and found that it could improve the specificity and accuracy of breast cancer.

Zhao et al[33] and Sayed et al[34] found the mean strain ratios were significantly higher in malignant than benign lesions and concluded that the strain ratio could be more objective to differentiate the masses when those masses were difficult to be judged by using 5-point scoring system in sonoelastographic images. Some other studies also showed that compression strain elastography could improve characterization of breast lesions as benign or malignant.[35–40]

According to our study evaluation of strain ratio of breast lesions in ultrasound elastography has significant sensitivity, specificity, positive predictive value and negative predictive value and accuracy in differentiation between benign and malignant breast lesions. Our study was also comparable to other similar studies. So we can conclude that ultrasound elastographic strain ratio of breast lesions provides quantitative elasticity information that can facilitate characterization of breast lesions and allowing sparing of invasive diagnostic procedures. Therefore, ultrasound elastography can be used as a sole diagnostic test with high accuracy and can improve the diagnostic yield of other tests when used in combination.

References

1. Goehring C, Morabia A. Epidemiology of Benign Breast Disease, with Special Attention to Histologic Types. Epidemiol Rev 1997; 19(2): 310–327.
2. Hakinson S, Hunter D. Breast cancer. In: Adam HO, Hunter D, Trichopoulos D (eds). Textbook of Cancer Epidemiology. New York, NY: Oxford University Press; 2002: 301–339.
3. Ferlay J, Shin HR, Bray F, Forman D, Mathers C, Parkin DM. Estimates of worldwide burden of cancer in 2008: GLOBOCAN 2008. Int J Cancer 2010; 127: 2893–2917.
4. Tabar L, Yen MF, Vitak B, Chen HH, Smith RA, Duffy SW. Mammography service screening and mortality in breast cancer patients: 20-year follow-up before and after introduction of screening. Lancet 2003; 361: 1405–1410.
5. Donegan WL. Evaluation of a palpable breast mass. N Engl J Med 1992; 327(13): 937–942.
6. Duncan III JL, Cederbom GJ, Champaign JL, Smetherman DH, King TA, Farr GH et al. Benign diagnosis by image-guided core-needle breast biopsy. Am Surg 2000; 66(1): 5–10.
7. Checka CM, Chun JE, Schnabel FR, Lee J, Toth H. The relationship of mammographic density and age: implications for breast cancer screening. Am J Roentgenol 2012; 198(3): W292–295.
8. Kaplan SS. Clinical utility of bilateral whole-breast US in the evaluation of women with dense breast tissue. Radiology 2001; 221: 641–649.
9. Zonderland HM, Coerkamp EG, Hermans J, van de Vijver MJ, van Voorthuisen AE. Diagnosis of breast cancer: contribution of US as an adjunct to mammography. Radiology 1999; 213(2): 413–422.
10. Lister D, Evans AJ, Burrell HC, Blamey RW, Wilson AR, Pinder SE et al. The accuracy of breast ultrasound in the evaluation of clinically benign discrete, symptomatic breast lumps. Clin Radiol 1998; 53(7): 490–492.
11. Stavros AT, Thickman D, Rapp CL, Dennis MA, Parker SH, Sisney GA. Solid breast nodules: use of sonography to distinguish between benign and malignant lesions. Radiology 1995; 196(1): 123–134.
12. Berg WA. Supplemental screening sonography in

dense breasts. Radiol Clin North Am 2004; 142(5): 845–851.

13. Corsetti V, Ferrari A, Ghirardi M, Bergonzini R, Bellarosa S, Angelini O et al. Role of ultrasonography in detecting mammographically occult breast carcinoma in women with dense breasts. Radiol Med 2006; 111: 440–448.

14. Houssami N, Irwig L, Simpson JM, McKessar M, Blome S, Noakes J. Sydney Breast Imaging Accuracy Study: comparative sensitivity and specificity of mammography and sonography in young women with symptoms. Am J Roentgenol 2003; 180(4): 935–940.

15. Frey H. Real time elastography. A new ultrasound procedure for the reconstruction of tissue elasticity. Der Radiologe 2003; 43(10): 850–855.

16. Thomas A, Kümmel S, Fritzsche F, Warm M, Ebert B, Hamm B et al. Real-time sonoelastography performed in addition to B-mode ultrasound and mammography: improved differentiation of breast lesions? Acad Radiol 2006; 13(12): 1496–1504.

17. Thomas A, Degenhardt F, Farrokh A, Wojcinski S, Slowinski T, Fischer T. Significant differentiation of focal breast lesions: calculation of strain ratio in breast sonoelastography. Acad Radiol 2010; 17(5): 558–563.

18. Wojcinski S, Farrokh A, Weber S, Thomas A, Fischer T, Slowinski T et al. Multicenter study of ultrasound real-time tissue elastography in 779 cases for the assessment of breast lesions: improved diagnostic performance by combining the BI-RADS®-US classification system with sonoelastography. Ultraschall Med 2010; 31(5): 484–491.

19. Hall TJ, Zhu Y, CS Spalding CS. In vivo real-time freehand palpation imaging. Ultrasound Med Biol 2003; 29(3): 427–435.

20. Kumm TR, Szabunio MM. Elastography for the characterization of breast lesions: initial clinical experience. Cancer Control 2010; 17(3): 156–161.

21. Rahbar G, Sie AC, Hansen GC, Prince JS, Melany ML, Reynolds HE et al. Benign versus malignant solid breast masses: US differentiation. Radiology 1999; 213(3): 889−894 .

22. Singh K, Azad T, Gupta GD. The Accuracy of Ultrasound in Diagnosis of Palpable Breast Lumps. Breast 2008; 6(6): 100.

23. Dennis MA, parker SH, Klaus AJ, Stavros AT, Kaske TI, Clark SB. Breast biopsy Avoidance; the value of normal mammograms and normal sonograms in the setting of a palpable lump. Radiology 2001; 219(1): 186−191.

24. Weinstein SP, Conant EF, Orel SG, Zuckerman JA, Czerniecki B, Lawton TJ. Retrospective review of palpable breast lesions after negative mammography and sonography. J Women's Imaging 2000; 2: 15−18.

25. Vlaisavljevic V. Differentiation of solid breast tumours on the basis of their primary echographic characteristics as revealed by real time scanning of the uncompressed breast', Ultrasound Med Biol 1988; 14: 75−80.

26. Pande AR, Lohani B, Sayami P, Pradhan S. Predictive value of ultrasonography in the diagnosis of palpable breast lump. Kathmandu Univ Med J. 2003; 1(2): 78−84.

27. Evans A, Whelehan P, Thomson K, MacLean D, Brauer K, Purdie C et al. Quantitative shear wave ultrasound elastography: initial experience in solid breast masses. Breast Cancer Res 2010; 12(6):1−1.

28. Lee SH, Chang JM, Kim WH, Bae MS, Cho N, Yi A et al. Differentiation of benign from malignant solid breast masses: comparison of two-dimensional and three-dimensional shear-wave elastography. Eur Radiol 2013; 23: 1015–1026.

29. Mansour SM, Omar OS. Elastography ultrasound and questionable breast lesions: does it count? Eur J Radiol 2012; 81(11): 3234–3244.

30. Fischer T, Peisker U, Fiedor S, Slowinski T, Wedemeyer P, Diekmann F et al. Significant differentiation of focal breast lesions: raw data-based calculation of strain ratio. Ultraschall Med 2012; 33(4): 372–379.

31. Alhabshi SM, Rahmat K, Halim NA, Aziz S, Radhika S, Gan GC et al. Semi-quantitative and qualitative assessment of breast ultrasound elastography in differentiating between malignant and benign lesions. Ultrasound Med Biol 2013; 39(4): 568–578.

32. Zhang H, Qin D, Yang Z, Wang K, Sun F, Li B et al. Comparison of diffuse optical tomography, ultrasound elastography and mammography in the diagnosis of breast tumors. Ultrasound Med Biol 2014; 40(1): 1−10.

33. Zhao QL, Ruan LT, Zhang H, Yin YM, Duan SX. Diagnosis of solid breast lesions by elastography 5-point score and strain ratio method. Eur J Radiol 2012; 81(11): 3245–3249.

34. Sayed A, Layne G, Abraham J, Mukdadi O. Nonlinear characterization of breast cancer using multi-compression 3D ultrasound elastography in vivo. Ultrasonics 2013; 53 (5): 979–991.

35. Sadigh, G, Carlos RC, Neal CH, Dwamena BA. Accuracy of quantitative ultrasound elastography for differtiation of malignant and benign breast abnormalities : A meta-analysis. Breast Cancer Res Treat 2012; 134: 923−931.

36. Barr RG. Real-time ultrasound elasticity of the breast: Initial clinical results. Ultrasound Quarterly 2010; 26(2): 61−66.

37. Barr RG, Destounis S, Lackey LB, Svensson WE, Balleyguier C, Smith C. Evaluation of breast lesions using ultrasound elasticity imaging: A multicenter trial. J Ultrasound Med 2012; 31(2): 281–287.

38. Barr RG, Lackey AE. Predictive value of the "bull's eye" artifact on breast elasticity imaging in reducing breast lesion biopsy rate. Ultrasound Quarterly 2011; 27(3): 151−155.

39. Tanter M, Bercoff J, Athanasiou A, Deffieux T, Gennisson JL, Montaldo G et al. Quantitative assessment of breast lesion viscoelasticity: Initial clinical results using supersonic shear imaging. Ultrasound in Med & Biol 2008; 34(9): 1373−1386.

40. Berg WA, Cosgrove DO, Dore CJ, Schafer FK, Svensson WE, Hooley RJ et al. Shear-wave elastography improves the specificity of breast US: The BE1 multinational study of 939 masses. Radiology 2012; 262(2): 435−449.