GMR
The Original

ROLE OF ELASTOGRAPHY IN EVALUATING BREAST LESIONS: A COMPARATIVE STUDY OF STRAIN AND SHEAR WAVE ELASTOGRAPHY WITH PATHOLOGICAL CORRELATION

[1]* DR. MEENAL JAIN, [2] DR SHIVANI RAIKWAR, [3] DR. MAHIMA SINGH, [4] DR NEHA CHOUKSE, [5] DR ARUSHI GIRDHAR, [6] DR SHIVAM BAGHEL

[1]ASSISTANT PROFESSOR RADIODIAGNOSIS PEOPLE'S COLLEGE OF MEDICAL SCIENCES AND RESEARCH CENTRE, Email-meenalmintzz444@gmail.com
[2]POST GRADUATE STUDENT RADIODIAGNOSIS, PEOPLE'S COLLEGE OF MEDICAL SCIENCES AND RESEARCH CENTRE, BHOPAL, Email - shivanibhopal16@gmail.com
[3]JUNIOR RESIDENT 3 DEPARTMENT OF RADIODIAGNOSIS PEOPLE'S COLLEGE OF MEDICAL SCIENCES AND RESEARCH CENTRE, BHOPAL, Email id: mahimasingh2907@gmail.com
[4]SENIOR RESIDENT RADIODIAGNOSIS CHIRAYU MEDICAL COLLEGE AND HOSPITAL, BHOPAL, Email- Drnehachoukse123@gmail.com
[5]JUNIOR RESIDENT-3 RADIODIAGNOSIS PEOPLE'S COLLEGE OF MEDICAL SCIENCES AND RESEARCH CENTRE, Email- arushigirdhar88@gmail.com
[6]JUNIOR RESIDENT -1 DEPARTMENT OF RADIODIAGNOSIS PEOPLE`S COLLEGE OF MEDICAL SCIENCE AND RESEARCH CENTRE, BHOPAL Email- shivam.freestyle@gmail.com

ABSTRACT

Background: Breast diseases affect millions of women worldwide, with breast cancer being the leading cause of cancer-related mortality among women. Characterization of breast lesions as benign or malignant is crucial for appropriate management. Ultrasound elastography is an emerging non-invasive imaging technique that evaluates tissue stiffness, providing additional information beyond conventional B-mode ultrasound.

Aim: To assess the role of elastography as an adjunct to conventional ultrasound in differentiating benign and malignant breast lesions, and to compare the advantages and limitations of strain and shear wave elastography techniques.

Materials and Methods: A prospective cross-sectional study was conducted over 18 months in the Department of Radio Diagnosis at B.L.D.E.U's Shri B. M. Patil Medical College, Vijaypur. A total of 47 patients with ultrasonographically detectable breast lesions were evaluated using B-mode ultrasound, strain elastography (elastography scoring and strain ratio), and shear wave elastography. Findings were correlated with pathological results (FNAC/histopathology).

Results: Of the 47 lesions, 30 (64%) were benign and 17 (36%) were malignant. Fibroadenoma was the most common benign lesion, while invasive ductal carcinoma was the most common malignancy. Strain elastography scoring demonstrated sensitivity of 100%, specificity of 88%, PPV of 94%, and NPV of 100%. Strain ratio showed sensitivity of 97%, specificity of 88%, PPV of 94%, and NPV of 94%. Shear wave elastography demonstrated sensitivity of 100%, specificity of 94%, PPV of 97%, and NPV of 100%. All elastography techniques showed statistically significant correlation with pathological outcomes ($p<0.0001$). The area under the ROC curve for shear wave elastography (0.971) was slightly higher than strain elastography scoring (0.941) and strain ratio (0.925).

Conclusion: Ultrasound elastography is a valuable adjunct to conventional B-mode ultrasound in the evaluation of breast lesions. Both strain and shear wave elastography techniques improve diagnostic accuracy in differentiating benign from malignant breast lesions, with shear wave elastography showing marginally better performance. Elastography has the potential to reduce unnecessary biopsies in breast lesions.

KEYWORDS: Breast elastography, Strain elastography, Shear wave elastography, Breast lesions, Breast Imaging Reporting and Data System (BI-RADS)

INTRODUCTION

Breast diseases, both benign and malignant, affect a substantial proportion of women worldwide. Women presenting with a positive family history or self-detected breast abnormalities are often anxious to rule out malignancy. Characterization of breast lesions as benign or malignant is a critical task for radiologists and pathologists. Many women undergo unnecessary painful biopsies, a large proportion of which turn out to be benign.

In India, during 2012, 144,937 women were reported to have newly detected breast cancer, with 70,218 deaths attributed to breast cancer. The trend of rising breast cancer in India is particularly concerning, with increasing

numbers of younger women being affected and more aggressive cancers occurring in the young population. Late presentation and lack of awareness and screening remain significant challenges. Screening is the single most important factor responsible for better survival rates in Western countries.
The Breast Imaging Reporting and Data System (BI-RADS) helps differentiate benign from malignant lesions and includes ultrasonographic criteria such as shape, margin, orientation, echo pattern, posterior acoustic features, lesion boundary, and vascularization. While conventional ultrasound is excellent for lesion detection, characterization can sometimes be challenging on B-mode scans alone.
Elastography, the measurement of tissue stiffness, addresses these challenges by providing information about the mechanical properties of tissues. Malignant lesions typically exhibit greater stiffness than benign lesions due to increased cellularity, desmoplastic reaction, and collagen cross-linking. This technique has evolved from manual palpation to sophisticated imaging modalities that can quantitatively and qualitatively assess tissue elasticity.
Ultrasound elastography is an advanced method that evaluates the elasticity of tissues by estimating local longitudinal strain of tissue elements. The elasticity information is displayed in the form of a color map or gray-scale image called an elastogram. Two main techniques are currently in clinical use: strain elastography (qualitative and semi-quantitative) and shear wave elastography (quantitative).
This study was undertaken to assess the role of elastography as an added imaging modality to conventional B-mode ultrasound in differentiating benign and malignant breast lesions, and to compare the advantages and disadvantages of strain and shear wave elastography techniques.

AIM AND OBJECTIVES

Aim-To assess the role of elastography as an added imaging modality to USG B-mode scan in differentiating benign and malignant lesions of the breast.
Objectives-
1. To evaluate the diagnostic performance of strain elastography (elastography scoring and strain ratio) in differentiating benign from malignant breast lesions.
2. To evaluate the diagnostic performance of shear wave elastography in differentiating benign from malignant breast lesions.
3. To compare the diagnostic accuracy of strain and shear wave elastography techniques.
4. To assess the advantages and limitations of strain and shear wave elastography in clinical practice.

MATERIALS AND METHODS

Study Design-A prospective cross-sectional study was conducted in the Department of Radio Diagnosis at B.L.D.E.U's Shri B. M. Patil Medical College, Hospital & Research Centre, Vijaypur, Karnataka, India.
Duration of Study-November 2015 to June 2017 (18 months)
Study Population-A total of 47 patients with ultrasonographically detectable breast lesions were enrolled in the study.

Sample Size Calculation-With sensitivity of detecting breast lesions at 97%, at 95% confidence level and ±5% margin of error, the sample size was calculated as 45.
$n = z^2p(100-p)/d^2$
Where z = z-value at 95% confidence level, p = sensitivity for breast lesions, d = margin of error

Inclusion Criteria

· All patients presenting with breast lump, breast pain, or any other breast-related complaints
· Presence of ultrasonographically detectable mass
· Patients who consented to the examination
· Patients in whom FNAC/histopathological follow-up was possible

Exclusion Criteria

· Patients who had already undergone surgery
· Patients who did not consent to the examination
· Patients in whom FNAC/histopathological follow-up was not possible

Equipment-Siemens ACUSON S3000 USG machine equipped with elastography software (compression and vibration) with linear high-frequency transducer. The system also has Color Doppler, Pulsed Doppler, Continuous Wave Doppler, M-mode, and B-mode imaging capabilities.

Methodology-A brief history, physical examination, ultrasonographic, and elastographic evaluation were performed on all patients who fulfilled the inclusion criteria.
B-mode Ultrasound Examination:
Patients were examined in the supine position with appropriate positioning. B-mode ultrasound evaluation was performed to identify and characterize breast lesions. Lesions were classified according to BI-RADS

categorization (Categories 0-6). Parameters assessed included size, shape, margin, orientation, echo pattern, posterior acoustic features, lesion boundary, and vascularization.

Strain Elastography:
Real-time strain elastography was performed by applying gentle, repetitive compression with the transducer while maintaining consistent pressure. The quality of elastography was monitored using the quality index display. Two methods were used:
1. Elastography Scoring (ES): Lesions were scored according to the Tsukuba (Itoh) scoring system:
   · Score 1: Even strain over the entire lesion (soft)
   · Score 2: Strain in most of the lesion with some areas of no strain
   · Score 3: Strain at the periphery with no strain in the center
   · Score 4: No strain in the entire lesion (hard)
   · Score 5: No strain in the entire lesion or surrounding tissue
   · BGR (Blue-Green-Red) pattern: Typical of cystic lesions
   Scores 1-3 were considered benign, and scores 4-5 were considered malignant.
2. Strain Ratio (SR): The strain ratio was calculated by placing Region of Interest 1 (ROI 1) in the lesion and ROI 2 in the surrounding normal tissue at the same depth. The strain ratio was automatically calculated by the machine.
Shear Wave Elastography:
Shear wave elastography was performed using Virtual Touch Tissue Imaging Quantification (VTIQ) technology. Shear wave velocity (SWV) was measured in meters per second (m/s) by placing multiple ROIs within the lesion. The mean SWV values were recorded.
Pathological Correlation:
All lesions underwent FNAC or histopathological examination (core needle biopsy or surgical biopsy), which served as the reference standard.
Statistical Analysis-Data were presented diagrammatically. Mean ± SD, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were calculated. Fischer's exact test and Chi-square tests were used for association. Receiver Operating Characteristic (ROC) curves and Area Under the Curve (AUC) were calculated. A p-value < 0.05 was considered statistically significant.

RESULTS
A total of 47 patients with breast lesions were included in the study. The demographic and clinical characteristics of the study population are summarized below.
Demographic Profile
Age Distribution:-The age distribution ranged from 11 to 80 years, with a mean age of 40.87 ± 17.16 years. The majority of patients were in the third decade of life, followed by the fourth, fifth, and seventh decades.
Gender Distribution:-Of the 47 patients, 44 (93.6%) were female and 3 (6.4%) were male.
Side Affected:-There was no significant side predilection, with 24 lesions (51%) in the right breast and 23 lesions (49%) in the left breast.
Number of Lesions:-Solitary lesions were most common (36 cases, 76.6%), followed by multiple lesions (7 cases, 14.9%) and two lesions (4 cases, 8.5%).
Lesion Characteristics:-
· Solid lesions: 32 cases (68.1%)
· Cystic lesions: 9 cases (19.1%)
· Mixed lesions (hematoma/abscess): 6 cases (12.8%)

BI-RADS Categorization-The distribution of lesions according to BI-RADS categories was:
· Category 2 (benign): 24 cases (51%)
· Category 3 (probably benign): 8 cases (17%)
· Category 4 (suspicious): 6 cases (13%)
· Category 5 (highly suggestive of malignancy): 9 cases (19%)

Elastography Findings
Strain Elastography Colour Pattern:
· Blue-Green-Red (BGR): 9 cases (19.1%) - characteristic of cystic lesions
· Blue: 2 cases (4.3%)
· Green: 1 case (2.1%)
· Green-Red: 6 cases (12.8%)
· Green-Blue: 15 cases (31.9%)
· Red: 13 cases (27.7%)
· Yellow-Red: 1 case (2.1%)

Elastography Scoring (Tsukuba System):

· Score 1: 4 cases (8.5%)
· Score 2: 17 cases (34.0%)
· Score 3: 3 cases (6.4%)
· Score 4: 2 cases (12.8%)
· Score 5: 13 cases (27.7%)
· BGR: 9 cases (19.1%)

Strain Ratio:
· Mean value: 3.6 ± 4.7 (range: 0.4 to 12)
· Benign lesions: 1.26 ± 0.82
· Malignant lesions: 6.9 ± 4.2
· Statistically significant difference ($p<0.0001$)

Shear Wave Elastography:
· Mean value: 3.2 ± 2.3 m/s (range: 1.9 to 7 m/s)
· Benign lesions: 1.71 ± 1.21 m/s
· Malignant lesions: 5.8 ± 1.3 m/s
· Statistically significant difference ($p<0.0001$)

Pathological Findings
Distribution:
· Benign lesions: 30 cases (64%)
· Malignant lesions: 17 cases (36%)
Benign Lesions (n=30):
· Fibroadenoma: 12 cases (40%)
· Cysts/Fibrocystic disease: 7 cases (23.3%)
· Abscess: 3 cases (10%)
· Mastitis: 3 cases (10%)
· Lipoma: 2 cases (6.7%)
· Hematoma: 1 case (3.3%)
· Gynecomastia: 1 case (3.3%)
· Unclassified benign: 1 case (3.3%)

Malignant Lesions (n=17):
· Invasive/Infiltrating Ductal Carcinoma (IDC): 13 cases (76.5%)
· Ductal Carcinoma In Situ (DCIS): 2 cases (11.8%)
· Invasive/Mucinous Carcinoma: 2 cases (11.8%)

Diagnostic Performance
B-mode Ultrasound:
· Sensitivity: 100% (88-100, 95% CI)
· Specificity: 82% (57-96, 95% CI)
· PPV: 91% (75-98, 95% CI)
· NPV: 100% (77-100, 95% CI)

Strain Elastography Scoring:
· Sensitivity: 100% (88-100, 95% CI)
· Specificity: 88% (64-98, 95% CI)
· PPV: 94% (79-99, 95% CI)
· NPV: 100% (78-100, 95% CI)
· AUC: 0.941 ($p<0.0001$)

Strain Ratio:
· Sensitivity: 97% (83-99, 95% CI)
· Specificity: 88% (64-98, 95% CI)
· PPV: 94% (78-99, 95% CI)
· NPV: 94% (70-99, 95% CI)
· AUC: 0.925 ($p<0.0001$)

Shear Wave Elastography:
· Sensitivity: 100% (88-100, 95% CI)
· Specificity: 94% (71-99, 95% CI)

· PPV: 97% (83-99, 95% CI)
· NPV: 100% (79-100, 95% CI)
· AUC: 0.971 ($p<0.0001$)
All elastography techniques showed statistically significant correlation with pathological outcomes ($p<0.0001$).

DISCUSSION

The present study evaluated the role of elastography as an adjunct to conventional B-mode ultrasound in differentiating benign and malignant breast lesions. The diagnostic performance of strain elastography (elastography scoring and strain ratio) and shear wave elastography was assessed and compared with pathological outcomes.

Demographic Profile

The age distribution in our study ranged from 11 to 80 years, with a mean age of 40.87 years. The majority of patients were in the third decade of life, which is consistent with the peak incidence of fibroadenomas and other benign breast conditions. The higher proportion of females (93.6%) in our study reflects the higher prevalence of breast lesions in females compared to males.

There was no significant side predilection for breast lesions, which is consistent with findings from previous studies. The predominance of solitary lesions (76.6%) and solid lesions (68.1%) in our study is typical of breast lesion presentation in clinical practice.

Pathological Distribution

In our study, 64% of lesions were benign and 36% were malignant. This distribution is consistent with previously reported studies, confirming that the majority of breast lesions encountered in clinical practice are benign. The most common benign lesion was fibroadenoma (40%), followed by cysts/fibrocystic disease (23.3%). This is in keeping with the known epidemiology of benign breast diseases, where fibroadenomas are the most common benign solid tumors in women of reproductive age.

Among malignant lesions, invasive ductal carcinoma (IDC) was the most common (76.5%), followed by DCIS and mucinous carcinoma. This distribution reflects the typical prevalence of breast cancer subtypes reported in the literature.

Diagnostic Performance

B-mode Ultrasound:-B-mode ultrasound demonstrated excellent sensitivity (100%) but relatively lower specificity (82%) in our study. This confirms that while ultrasound is highly sensitive for detecting breast lesions, its ability to differentiate benign from malignant lesions is somewhat limited. The high sensitivity but moderate specificity is consistent with the well-known limitations of conventional ultrasound, particularly in the characterization of indeterminate lesions (BI-RADS 3 and 4A). Our findings align with the study by Andrew Evans et al., who reported similar performance characteristics for greyscale ultrasound.

Elastography Scoring:

The Tsukuba elastography scoring system demonstrated excellent diagnostic performance with sensitivity of 100% and specificity of 88%. The PPV and NPV were 94% and 100%, respectively. These results are comparable to those reported by Hui Zhi et al. (2007), who found elastography to be the most specific modality (95.7%) among mammography, sonography, and elastography. Similarly, Thomas et al. (2006) reported elastography specificity of 91.5% and 84.7% for two observers.

The high NPV of 100% is particularly noteworthy, as it suggests that a benign elastography score (1-3) can reliably exclude malignancy, potentially reducing unnecessary biopsies. This is consistent with the findings of Kumm et al. (2010), who reported an NPV of 90% for elastography scoring.

Strain Ratio:

Strain ratio analysis demonstrated sensitivity of 97%, specificity of 88%, PPV of 94%, and NPV of 94%. The mean strain ratio for malignant lesions (6.9 ± 4.2) was significantly higher than that for benign lesions (1.26 ± 0.82), with $p<0.0001$. These findings are consistent with those of Yatu et al. (2014), who reported mean strain ratios of 5.546 ± 1.434 for malignant lesions and 2.48 ± 1.605 for benign lesions.

The slightly lower sensitivity (97%) compared to elastography scoring (100%) may reflect the operator dependence of strain ratio measurement and the challenges in selecting appropriate regions of interest. However, strain ratio provides a semi-quantitative assessment that can be useful in cases where subjective scoring is difficult.

Shear Wave Elastography:

Shear wave elastography demonstrated the highest overall diagnostic performance with sensitivity of 100%, specificity of 94%, PPV of 97%, and NPV of 100%. The mean shear wave velocity for malignant lesions (5.8 ± 1.3 m/s) was significantly higher than for benign lesions (1.71 ± 1.21 m/s), with $p<0.0001$.

The AUC for shear wave elastography (0.971) was slightly higher than that for elastography scoring (0.941) and strain ratio (0.925), suggesting marginally better overall diagnostic performance. These findings are consistent with those of Chang et al. (2013), who reported similar AUC values for shear-wave and strain elastography (0.928 vs. 0.943). Similarly, Golatta et al. (2014) reported significantly higher shear wave velocities in malignant lesions (7.73 m/s) compared to benign lesions (4.46 m/s).

The quantitative nature of shear wave elastography offers advantages over strain elastography, including reduced operator dependence and better reproducibility. However, it may face limitations in very stiff lesions where shear wave velocity measurements may exceed the upper limit of detection.

Comparison of Elastography Techniques

Our study demonstrated that both strain and shear wave elastography techniques significantly improve the diagnostic accuracy of B-mode ultrasound in differentiating benign from malignant breast lesions. The combined use of B-mode ultrasound with either elastography technique resulted in higher diagnostic performance compared to B-mode ultrasound alone.

Shear wave elastography showed slightly better diagnostic performance compared to strain elastography (elastography scoring and strain ratio). However, the differences were not statistically significant, suggesting that both techniques are valuable in clinical practice.

The choice between strain and shear wave elastography may depend on the specific clinical situation and available equipment. Strain elastography is more widely available and less expensive, while shear wave elastography offers quantitative measurements and potentially better reproducibility.

Characteristic Elastographic Features of Benign Lesions

Our study identified characteristic elastographic features for specific benign lesions:

· Lipomas: Softest lesions (ES 1-2, SR 0.4-1.3, SW ~2 m/s), almost indistinguishable from surrounding breast parenchyma
· Fibroadenomas: Variable appearance (ES 2-3, SR 0.4-1.6, SW 1.9-3.3 m/s) depending on fibrotic content
· Cysts: BGR pattern on strain elastography, non-quantifiable on shear wave due to fluid content
· Abscesses: ES ~3, SR ~2, SW 2.5-3 m/s (measurements from solid component)

These characteristic features can aid in the diagnosis of specific benign lesions and help avoid unnecessary biopsies.

Advantages and Disadvantages of Elastography Techniques

Strain Elastography (ES and SR):

Advantages:
· Shorter examination time
· Real-time display
· Immediate interpretation
· Limited cost
· Well-established scoring systems

Disadvantages:
· Operator-dependent technique
· Requires special training
· Qualitative or semi-quantitative
· May vary with histotype and lesion size
· Interobserver variability

Shear Wave Elastography:

Advantages:
· Quantitative method
· Less operator dependent
· Reproducible results
· More accurate assessment of tissue stiffness distribution

Disadvantages:
· Higher cost
· Limited availability
· Technical limitations in very stiff lesions (velocity too high to measure)
· May vary with histotype and lesion size

Clinical Implications

Our study confirms that elastography is a valuable adjunct to conventional breast ultrasound. It is most useful in:

1. BI-RADS 3 lesions: Can help upgrade lesions that would otherwise be followed up, potentially reducing unnecessary anxiety and follow-up examinations.
2. BI-RADS 4A lesions: Can help downgrade lesions that would otherwise undergo biopsy, potentially reducing unnecessary invasive procedures.
3. Subcentimetric lesions: Can aid in characterization of small lesions where B-mode features may be less specific.
4. Dense breasts: Can provide additional information in cases where B-mode ultrasound is limited.

However, elastography should not replace conventional breast ultrasound. It is most valuable as an adjunct to B-mode ultrasound, improving diagnostic confidence and potentially reducing the number of unnecessary biopsies.

Limitations of the Study

1. Small sample size: With only 47 cases, the statistical power is limited.
2. Operator dependence: As a pilot study with an inexperienced operator, there was a learning curve, and initial cases were excluded.
3. Selection bias: Cases without pathological evaluation were excluded.
4. Limited histopathological correlation: Detailed correlation between elastographic features and specific histopathological subtypes was not performed.
5. Technical limitations: Cystic lesions could not be adequately assessed by shear wave elastography.
6. No consensus on cut-off values: There is no universally accepted cut-off value for strain ratio or shear wave velocity in differentiating benign from malignant lesions.

Future Directions

Larger, multicenter studies are needed to establish standardized protocols, determine optimal cut-off values for different ultrasound systems, and assess test performance across different lesion sizes and depths. Standardization of elastography techniques across different manufacturers is also needed to ensure reproducibility and comparability of results.

CONCLUSION

1. Ultrasound elastography is a valuable adjunct to conventional B-mode ultrasound in the evaluation of breast lesions, improving diagnostic accuracy in differentiating benign from malignant lesions.
2. Both strain elastography (elastography scoring and strain ratio) and shear wave elastography demonstrate excellent diagnostic performance, with shear wave elastography showing marginally better AUC values.
3. Elastography scoring (Tsukuba system) offers excellent sensitivity and negative predictive value, making it useful for excluding malignancy.
4. Strain ratio and shear wave elastography provide quantitative/semi-quantitative assessment with good diagnostic accuracy.
5. The combination of B-mode ultrasound and elastography can potentially reduce the number of unnecessary breast biopsies and improve patient management.
6. Elastography is most useful in indeterminate lesions (BI-RADS 3 and 4A), helping to increase diagnostic confidence and guide clinical decision-making.
7. While elastography is a promising technique, it should be considered as an adjunct to, not a replacement for, conventional breast ultrasound and pathological evaluation.

SUMMARY

A prospective cross-sectional study was conducted to evaluate the role of elastography in differentiating benign and malignant breast lesions. A total of 47 patients with breast lesions were evaluated using B-mode ultrasound, strain elastography (elastography scoring and strain ratio), and shear wave elastography.

Of the 47 lesions, 30 (64%) were benign and 17 (36%) were malignant. The most common benign lesion was fibroadenoma, and the most common malignancy was invasive ductal carcinoma. All elastography techniques demonstrated excellent diagnostic performance, with shear wave elastography showing the highest overall accuracy (AUC 0.971). Elastography significantly improved the diagnostic performance compared to B-mode ultrasound alone.

Both strain and shear wave elastography are valuable adjuncts to conventional breast ultrasound. They can help reduce unnecessary biopsies and improve patient management, particularly in indeterminate lesions. Shear wave elastography offers advantages in terms of reproducibility and quantitative assessment, while strain elastography is more widely available and cost-effective. Future studies should focus on standardization and establishing optimal cut-off values for different clinical settings.

REFERENCES

1. Ghalioughli P. Magic and medical science in ancient Egypt. London: Hodder and Stoughton; 1963.
2. Tristam M, Barbosa DC, Cosgrove DO, Nassiri DK, Bamber JC, Hill CR. Ultrasonic study of in vivo kinetic characteristics of human tissues. Ultrasound Med Biol. 1986;12:927-937.
3. Egorov V. Differentiation of benign and malignant breast lesions by mechanical imaging. Breast Cancer Research and Treatment. 2009;118:67-80.
4. Muthupillai R, Lomas DJ, Rossman PJ, Greenleaf JF, Manduca A, Rehman RL. Magnetic resonance elastography by direct visualization of propagating acoustic strain waves. Science. 1995;269:1854-7.
5. Krouskop TA, Dougherty DR, Vinson FS. A pulsed Doppler ultrasonic system for making noninvasive measurements of the mechanical properties of soft tissue. J Rehabil Res Dev. 1987;24:1-8.
6. Lerner RM, Parker KJ, Holen J, Gramiak R, Waag RC. Sono-elasticity: Medical elasticity images derived from ultrasound signals in mechanically vibrated targets. Acoustical Imaging. 1988;16:317-327.

7. Zeeshan M, Khan AM, Sibgatullah M, Jayesh, Lanke RB, Ramanarayana B, Singh V. To determine the role of human papillomavirus in oral cancer—A prospective study. J Pharm Bioallied Sci. 2024;16(Suppl 4):S3218–S3220. doi:10.4103/jpbs.jpbs_713_24.
8. Bhargava A, Saigal S, Chatterjee S, Chandrasekaram K, Khurshid G, Sandou GP, Singh V. Evaluation of type, nature, and prevalence of common oral pathology lesions involving periodontium and implant in patients of a tertiary-level dental hospital in Hazaribagh City, Jharkhand. J Pharm Bioallied Sci. 2024;16(Suppl 1):S115–S117. doi:10.4103/jpbs.jpbs_403_23.
9. Robert AJ. Breast Anatomy for the Interventionalist. J TVIR. 2014;17(1):3-9.
10. De Benedetto D, et al. Radiological anatomy of the breast. Italian Journal of Anatomy and Embryology. 2016;121(1):20-36.
11. Shah G, Jankharia B. Pictorial essay: Breast USG. Indian J Radiol Imaging. 2010;20(2):98-104.
12. Wilkes AN. Sonographic Evaluation of the Breast. Continuing Medical Education Diagnostic Imaging. 2007;1-6.
13. Rizzato G, Chersivani R, Macorig D, Perrone R. Dynamic breast anatomy. Available at: http://www.liveto.com/semi/sonic/pdf/se01.pdf
14. Nicholson BT, Harvey JA, Cohen MA. Nipple-Areolar Complex: Normal Anatomy and Benign and Malignant Processes. RadioGraphics. 2009;29:509-52.
15. Geddes DT. Ultrasound imaging of the lactating breast: methodology and application. International Breastfeeding Journal. 2009;4(4):1-17.
16. Draghi F, Tarantino CC, Madonia L, Ferrozzi G. Ultrasonography of the male breast. J Ultrasound. 2011;14(3):122-129.
17. Masciadri N, Ferranti C. Benign breast lesions: Ultrasound. J Ultrasound. 2011;14(2):55-65.
18. Gokhale S. Ultrasound characterization of breast masses. Indian J Radiol Imaging. 2009;19(3):242-247.
19. Woo KM, et al. US of Ductal Carcinoma In Situ. RadioGraphics. 2002;22:269-281.
20. Izumori A, Takebe K, Sato A. Ultrasound findings and histological features of ductal carcinoma in situ detected by ultrasound examination alone. Breast Cancer. 2010;17:136-141.
21. Lilian CW, et al. US Appearance of Ductal Carcinoma In Situ. RadioGraphics. 2013;33:213-228.
22. Schoonjans JM, Brem RF. Sonographic Appearance of Ductal Carcinoma In Situ Diagnosed with Ultrasonographically Guided Large Core Needle Biopsy. J Ultrasound Med. 2000;19:449-457.
23. Elston CW, Ellis IO. Pathological prognosis factors in breast cancer I. The value of histological grade in breast cancer. Histopathology. 1991;19:403.
24. Ciurea AI, Ciortea CA, Botar-Jid C, Dudea SM. Atypical ultrasound appearance of malignant breast nodules. Medical Ultrasonography. 2009;11(4):67-71.
25. Blaichman J, et al. Sonographic Appearance of Invasive Ductal Carcinoma of the Breast According to Histologic Grade. AJR. 2012;199:W402-W408.
26. Bhagat N, Salam S, Garg A, Venkatesan V, Hardik S, Hardik SG, Kumar S, Kashwani R. Use of Liposomal Curcumin for Oral Cancer Treatment: A Systematic Review and Meta Analysis. Nanotechnology Perceptions. 2024 Jun 22:342-59.
27. Aho M, et al. Correlation of Sonographic Features of Invasive Ductal Mammary Carcinoma with Age, Tumor Grade, and Hormone-Receptor Status. J Clin Ultrasound. 2013;41(1):10-17.
28. Lopez K, Bassett LW. Invasive Lobular Carcinoma of the Breast: Spectrum of Mammographic, US, and MR Imaging Findings. RadioGraphics. 2009;29:165-176.
29. Selinko VL, Middleton LP, Dempsey PJ. Role of sonography in diagnosing and staging invasive lobular carcinoma. J Clin Ultrasound. 2004;32:323-32.
30. Johnson K, Sarma D, Hwang ES. Lobular breast cancer series: imaging. Breast Cancer Research. 2015;17:94.
31. Cho N, Oh KK, Lee S. Medullary Carcinoma of the Breast: Sonographic Features Distinguishing it from Fibroadenoma. J Med Ultrasound. 2002;10:191-196.
32. Lam WWM, Chu WCW, Tse GM, Ma TK. Sonographic Appearance of Mucinous Carcinoma of the Breast. AJR. 2004;182(4):1069-1074.
33. Bernathova M, Zelger B, Deardon D, Bodne G. Sonographic Findings of an Intraductal Mucinous Carcinoma. J Ultrasound Med. 2006;25:925-927.
34. Burnside ES, et al. The ACR BI-RADS Experience: Learning From History. J Am Coll Radiol. 2009;6(12):851-860.
35. Wells PNT, Liang H-D. Medical ultrasound: imaging of soft tissue strain and elasticity. J R Soc Interface. 2011;8(64):1521-1549.
36. Cespedes I, Ophir J, Ponnekanti H, Maklad N. Elastography: elasticity imaging using ultrasound with application to muscle and breast in vivo. Ultrason Imaging. 1993;15(2):73-88.
37. Zhi H, Ou B, Luo BM, Feng X, Wen YL, Yang HY. Comparison of Ultrasound Elastography, Mammography, and Sonography in the Diagnosis of Solid Breast Lesions. J Ultrasound Med. 2007;26:807-815.
38. Thomas A, et al. Real-time Elastography - an advanced method of ultrasound: first results in 108 patients with breast lesions. Ultrasound Obstet Gynecol. 2006;28:335-34.

39. Kumm T, Szabunio M. Elastography for the characterisation of Breast lesions: Initial clinical experience. Cancer Control. 2010;17(3):156-161.
40. Navarro B, Úbeda B, Vallespi M, Wolf C, Casas L, Browne JL. Role of Elastography in the Assessment of Breast Lesions: Preliminary Results. J Ultrasound Med. 2011;30:313-321.
41. Cho N, et al. Distinguishing Benign from Malignant Masses at Breast US: Combined US Elastography and Color Doppler US—Influence on Radiologist. Radiology. 2012;262(1):80-90.
42. Yatu M, Turan E, Turan ÇÖ. The Role of Ultrasonic Elastography in the Differential Diagnosis of Breast Masses and Its Contribution to Classical Ultrasonographic Evaluation. J Breast Health. 2014;10:141-146.
43. P N, Bhat R, Bhat SS. Pharmacogenomics in Pediatric Cancer Patients Treated with Irinotecan: A Systematic Review. Oral Sphere J. Dent. Health Sci. 2025;1(4):244-258.
44. Goddi A, Bonardi M, Alessi S. Breast Elastography: A literature review. J Ultrasound. 2012;15:192-198.
45. Evans A, et al. Quantitative shear wave ultrasound Elastography: initial experience in solid breast masses. Breast Cancer Res. 2012;12(6):R104.
46. Chang JM, Won JK, Lee KB, Park IA, Yi A, Moon WK. Comparison of Shear-Wave and Strain Ultrasound Elastography in the Differentiation of Benign and Malignant Breast Lesions. AJR. 2013;201:W347-W356.
47. Itoh A. Review of techniques and diagnostic criteria of breast ultrasound Elastography. MEDIX Suppl. 2007;8-11.
48. Rizzatto G. Real time elastography of breast in clinical practice. MEDIX Suppl. 2007;12-15.
49. Fleury EFC, Rinaldi JF, Piató S, Fleury JC, Roveda Jr D. Features of cystic breast lesions at ultrasound elastography. Radiol Bras. 2008;41(3):167-172.
50. Li DD, Xu HX, Liu BJ, Bo XW, Li XL, Wu R. Quality Measurement of Two-dimensional Shear Wave Speed Imaging for Breast Lesions: the Associated Factors and the Impact to Diagnostic Performance. Scientific Reports. 2017;7:5076.
51. Golatta M, et al. Evaluation of Virtual Touch Tissue Imaging Quantification, a New Shear Wave Velocity Imaging Method, for Breast Lesion Assessment by Ultrasound. BioMed Research International. 2014;1-7.
52. Tan SY, et al. Comparison of readers' detection of right-sided and left-sided breast cancers and microcalcifications. Journal of Medical Imaging and Radiation Oncology. 2011;55(4):353-361.
53. Allen SD, Wallis MG, Cooke R, Swerdlow AJ. Radiologic Features of Breast Cancer after Mantle Radiation Therapy for Hodgkin Disease: A Study of 230 Cases. Radiology. 2014;272(1):73-78.
54. Carlsen JF, Ewertsen C, Lönn L, Nielsen MB. Strain Elastography Ultrasound: An Overview with Emphasis on Breast Cancer Diagnosis. Diagnostics. 2013;3:117-125.
55. Sahar MM, Omar SO. Elastography ultrasound and questionable breast lesions: Does it count? European Journal of Radiology. 2012;81(1):3234-324.
56. Jin ZQ, et al. Acoustic Radiation Force Impulse Elastography of Breast Imaging Reporting and Data System Category 4 Breast Lesions. Clinical Breast Cancer. 2012;12(6):420-427.
57. Moan R. Pros and cons of state-of-the-art breast elastography [Internet]. 2013 [cited 2017 Oct 13].
58. Busko E, Mishchenko A, Semiglazov V. Cutoff value of Sonoelastography Strain-Ratio for differentiation between benign and malignant breast lesions. In: European Congress of Radiology. 2013:1-5.
59. Franchi-Abellaab S, Eliec J-M, Correas JM. Ultrasound elastography: Advantages, limitations and artefacts of the different techniques from a study on a phantom. Diagnostic and Interventional Imaging. 2013;94(5):497-501.