Breast Sonography – 2D, 3D, 4D Ultrasound or Elastography?

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Keywords

Breast · Ultrasound · Three-dimensional imaging · Elastography · Breast Diseases

Summary

The aim of this publication is to give an answer to the question whether 2D, 3D and 4D sonography of the breast can be replaced by elastography or whether elastography is an adjunct tool to B-mode imaging. The Breast Imaging and Reporting Data System (BI-RADS) ultrasound (US) descriptors of a lesion besides vascularity are based on B-mode imaging. US elastography displays the mechanical tissue properties. This information can be obtained by freehand compression and decompression. Acoustic radiation force impulse imaging (ARFI) produces stress with low-frequency push pulses. Manual compression by the transducer is not necessary. Shear wave elastography (SWE) is the combination of ARFI and the measurement of the consecutive shear wave propagations in the tissue. A quantification of the elasticity in kilopascal (kPa) is offered. Discussing B-mode imaging and elastography combined with the literature, elastography is seen as an addition to B-mode imaging with the potential to increase the specificity of the B-mode imaging-based BI-RADS assessment. In spite of additional elasticity information, the sensitivity remains high. A time-saving diagnostic algorithm for 2D, 3D US and elastography is described. In conclusion, it must be said that elasticity is not a stand-alone US modality able to replace 2D and 3D sonography.

Schlüsselwörter

Brust · Ultraschall · Multidimensionaler Ultraschall · Elastographie · Brusterkrankungen

Zusammenfassung

Diese Publikation versucht die Frage zu beantworten, ob Elastographie den 2D-, 3D- und 4D-Ultraschall der Brust ersetzen kann oder ob die Elastographie als Zusatztechnik zur B-Mode-Bildgebung zum Einsatz kommt. Abgesehen von der Durchblutungsstudie eines Herdes basiert die Breast Imaging and Reporting Data System (BI-RADS)-Kriterienanalyse auf dem B-Mode. Sonoelastographie stellt die mechanischen Gewebeeigenschaften dar. Diese Information kann man durch Freihandkompression und Dekompression erhalten. Acoustic Radiation Force Impulse Imaging (ARFI) steigert den Druck auf das Gewebe durch Einstrahlung eines Push-Pulses mit niedriger Frequenz. Eine manuelle Kompression mit dem Schallkopf ist dafür nicht erforderlich. Scherwellenelastographie (SWE) funktioniert auf der Basis von ARFI und den daraus resultierenden Scherwellengeschwindigkeitsmessungen im Gewebe. Die Quantifizierung der Gewebeelastizität wird in Kilopascal (kPa) angegeben. In Zusammenschau mit der Literatur ist die Elastographie als Zusatztechnik zur B-Mode-Bildgebung zu bewerten, wobei sie das Potenzial hat, die Spezifität des BI-RADS-Assessments zu steigern. Trotz zusätzlicher Elastographie bleibt die Sensitivität hoch. Ein zeitsparender diagnostischer Algorithmus von 2D- und 3D-Ultraschall mit zusätzlichem Einsatz der Elastographie wird vorgestellt. Abschließend ist zu sagen, dass die Elastographie die 2D- und 3D-Sonographie nicht ersetzt.

Introduction

Modern two-dimensional (2D), three-dimensional (3D) and four-dimensional (4D) ultrasound (US) technologies offer a wide range of different access options to study breast lesions. Color Doppler US has proven to be helpful in differentiating

benign from malignant breast masses. The latest technical development to analyze a breast lesion is based on elastography. Shortages of investigation time and high examination rates cause a tension between technical progress, economical aspects, and everyday practice. The question arises whether we need the whole number of US modalities of 2D, 3D, 4D

imaging and elastography or whether we can replace grey-scale imaging by using only elastography or vice versa. First, the different features of B-mode imaging and the different techniques of elastography are presented to create the basis for discussing the question above.

B-Mode Imaging

B-mode imaging is related to impedance differences in the tissue and offers grey-scale information of different tissue components. 2D, 3D and 4D studies can be performed by this technique. Progress in 2D high-frequency US transducer technology in combination with compound imaging and speckle reduction is the basis for high-quality 3D volume US [1, 2]. Modern breast US systems with broad-band high-frequency transducers, e.g. 6–16 MHz with full digital data management and high resolution combined with transmitter and receiver focusing, offer a high multidimensional imaging level. 4D US gives real-time 3D-rendered image information. In addition to conventional 2D sonography, 3D US provides new diagnostic information such as the ability to study a breast mass and the surrounding tissue in 3 orthogonal planes. The US Breast Imaging and Reporting Data System (BI-RADS) published by the American College of Radiology [3] and the US BI-RADS-analog version of the German, Austrian, and Swiss US Societies (DEGUM, OEGUM, SGUM) [4] are mainly based on morphological criteria discussing lesion shape, orientation, margin, lesion boundary, echo pattern, and posterior acoustic features. The growth pattern analysis of a breast lesion in the coronal plane (offered by 3D US) is implemented in the US BI-RADS-analog version. The different BI-RADS descriptors have the aim first to assess and then to classify the US-visible lesion.

Using a precise 2D US examination technique (meander-like scanning, radial or anti-radial scanning) with overlapping scans, moderate breast tissue compression and holding the scanner perpendicular to the skin surface is the basis for detecting small non-palpable breast lesions, complementarily to mammography or used as a first-line imaging tool [5–9]. Compound imaging is able to reduce numerous shadowing artifacts in the normal breast. Automated tissue optimization and tissue-harmonic imaging [10] help to present anatomy and pathology with enhanced contrast in order to optimize the image quality.

Lesion detection with 2D US is followed by the acquisition of a static 3D volume US dataset of the lesion and the surrounding tissue, in order to assess the breast lesion related to the US BI-RADS descriptors. The static 3D US information is presented in the multiplanar display mode. In the A- or B-plane of this mode (both planes are accessible to 2D scanning), the lesion will be rotated around the y-axis. Compared with 2D imaging, a static 3D US volume offers more information, e.g. the additional coronal view, and is suitable for

double reading. In the coronal plane, the lesion is analyzed for signs of compression or star/retraction pattern [11–13].

If the contrast between lesion and surrounding breast tissue is poor, 3D static volume contrast imaging (VCI) (GE Healthcare Austria GmbH, Zipf, Austria) enhances the contrast, with the aim to optimize the contours for making accurate BI-RADS assessment with correct differential criteria analysis. Static VCI provides a static 3D dataset with preselected slice thickness in all 3 planes and in different rendering modes. The surface rendering mode supports the assessment of inner cyst wall structures, e.g. a papilloma or an intraductal tumor outlined by echo-poor fluid. Echo-poor breast lesions can be rendered by inversion-mode technology. The volume of interest (VOI) has to cover the entire lesion. The inversion rendering mode presents the lesion in a 50% mixed surface smooth and 50% gradient light algorithm as a white-colored 3D model. It offers quick access to the 3D shape of an echo-poor lesion.

A 3D volume dataset displayed in a multiplanar view is the perfect basis to measure the long axes distances in all 3 perpendicular planes. No lesion measurement failure that may be obtained by 2D cross-sectional measurements can influence the results. Afterwards, the volume of the lesion is calculated by VoCal [11, 13–15]. For follow-up investigations, the long axes measurements and the volume measurement in milliliter (ml) are available. The most comprehensive documentation of a lesion can be performed with tomographic US imaging (TUI) (fig. 1). It is based on a 3D volume dataset. A topogram shows the position of the slices obtained from the 3D dataset. The distance between the different slices is adjusted to the lesion size in order to cover the entire lesion.

4D US means to study movements of three-dimensionally displayed objects. Movement in the breast may originate from compression and decompression of breast tissue and the lesion to analyze lesion elasticity and lesion movability, or may come from transducer movements comparable with 2D US scanning.

The panoramic scan technique is based on 2D B-mode imaging, which can be used for a precise documentation of a lesion in the breast with 1 image [16, 17]. In the radial scan direction (duct parallel), the shortest distance between the lesion and the nipple (lesion-nipple distance) will be measured, followed by the shortest-distance measurement between lesion and skin (lesion-skin distance). The breast pictogram tells whether it is the right or the left breast. The position of the radial transducer path towards the lesion is documented by the transducer icon in the breast pictogram, using the clock for description.

Elastography

The background for implementing elastography into the daily diagnostic US practice is given by the fact that malignancies have the tendency to harden the breast tissue. Elastography

Fig. 1. TUI documentation with the topogram and the following cross-sections of a non-Hodgkin's lymphoma of the breast.

uses US to describe and to measure different degrees of stiffness in different tissues. In general, this technique is based on a 3-step method: Firstly, low-frequency vibration produces stress. Secondly, the strain in the tissue following the stress is presented on the monitor (typically in different colors related to the stiffness), and thirdly, parameters to describe the tissue stiffness are established. The freehand compression and decompression technique [18] is widely used in different US systems to produce stress in the tissue. The longitudinal strain is calculated and displayed in a superimposed color map with different colors for soft and hard tissue. The manual compression of the skin may additionally overlap with a lateral scanner slip that influences the elastography result [19]. As a consequence of this, the tissue compression is investigator dependent. Strong pressure influences the elasticity image. 4D-VCI studies work with freehand compression and decompression and offer the elasticity information in a defined slice thickness volume, with the aim to study the elastic properties of the lesion and the surrounding breast tissue within the entire slice. A developmental step towards less investigator dependency is based on the acoustic radiation force impulse imaging (ARFI) technique. The low frequency generated by the transducer produces push pulses stressing the tissue without freehand compression. The consecutive strain will be displayed on the monitor (Virtual Touch Tissue Imaging™, ACUSON, Siemens AG Healthcare, Erlangen, Germany).

The most standardized elastography technique measures the speed of waves propagating perpendicularly to the focused push pulses (= shear waves) generated by ARFI. The ShearWave™ elastography (SuperSonic Imagine, S.A., Aix-en-Provence, France) shows local elastic information and, in addition, offers a quantitative evaluation of tissue stiffness in kilopascal (kPa) [20]. The propagation speed of the shear waves is proportional to the tissue stiffness and can be measured in meter per second (m/s) and displayed as color map (fig. 2). The commercially available ShearWave™

Fig. 2. SWE of an invasive ductal breast cancer with skin infiltration; the white circle within the rectangular region of interest indicates the area of quantitative elasticity evaluation in kPa; the rectangular color map area describes the entire region tested for shear wave elasticity.

elastography is a new technology; therefore, mainly preliminary clinical results are currently available [21, 22].

Discussion

BI-RADS assessment of breast lesions is mainly based on US morphology. The BI-RADS descriptors are presented by B-mode grey-scale imaging, and the resulting BI-RADS score is predominantly influenced by B-mode information. Vascularity usually is displayed as a function of color Doppler US [23–29]. It is an additional feature in BI-RADS assessment [3, 4]. Recent publications investigate the question

whether elastography is able to enhance the true-positive and the true-negative results of breast lesions in addition to B-mode imaging. In most of the publications, elasticity is not studied as a stand-alone feature. It is used as a complementary technology to B-mode imaging [22, 30]. Based on the literature, the sensitivity of B-mode breast US varies from 57% to 97% and the specificity from 60% to 90%. This means that many factors are influencing the result. These factors are: education and experience of the investigator, the quality of the US equipment, and breast volume and structure. Education, experience, and technical equipment can be improved by teaching and using modern US systems. A state-of-the-art breast US unit combined with experienced investigators offers high sensitivity of 97%, specificity of 82%, a positive predictive value (ppv) of 71%, and a negative predictive value (npv) of 78% [30]. To analyze breast lesions with B-mode imaging means to collect mosaic stones and to put them together as a basis for the decision on BI-RADS 2 or 3, which means that no needle biopsy is necessary, or BI-RADS 4 or 5, with the typical consequence of core needle or vacuum aspiration biopsies [31–36]. Stavros et al. [31] evaluated different features of B-mode imaging that are indicative of a benign or malignant lesion. Beside the features of angular margins (sensitivity 83%, specificity 92%), microlobulation (sensitivity 75%, specificity 84%), and hypoechogenicity (sensitivity 69%, specificity 90%), all other lesion characteristics indicating a malignant lesion (spiculation, orientation, posterior shadowing, branch pattern, calcifications, duct extension) presented a sensitivity below 50%. Combinations of different characteristics that are implemented in the BI-RADS assessment are the basis of high sensitivity and acceptable specificity [35–37]. Concerning the interobserver variability [38, 39] of B-mode lesion characteristics, Lazarus et al. [38] reported substantial agreement for lesion shape, boundary and orientation, moderate agreement for the margin and the posterior acoustic features, and only poor agreement for the echo pattern. These interobserver studies may give an explanation for the higher number of false-positive results in B-mode imaging with a lower specificity compared to sensitivity.

The 3D US morphology [12–15, 36, 40, 41] of a breast lesion offers, in addition to the 2D US results, the coronal plane growth pattern information as a new mosaic stone. In the coronal plane, using the retraction/star pattern sign as an indicator for malignancy and the compression pattern sign for benignancy, a sensitivity of 91% is reported by Rotten et al. [40, 41], a specificity of 94%, a ppv of 87%, and an npv of 96%. In daily routine diagnostic work, 4D grey-scale US did not prove to enhance true-positive results or to reduce false-positive results. Elasticity information obtained by 4D-VCI studies based on freehand compression and decompression were of academic interest, but have not been integrated into the routine diagnostic workflow.

The statistical data of freehand elastography with compression and decompression are related to a scoring system pub-

lished by Itoh et al. [19]. A score of 1 indicates even strain for the lesion and the surrounding tissue, a score of 2 means strain in the lesion, a score of 3 shows strain in the periphery of the lesion but no strain in the lesion center, a score of 4 is characterized by a lesion without strain, and a score of 5 indicates no strain in the lesion and in the surrounding tissue or in the surrounding tissue. Using scores 1–3 for benign and scores 4 and 5 for malignant lesions, elasticity showed a sensitivity of 87% and a specificity of 90%. In the publication of Hatzung et al. [30], the same score system was applied, but they found the highest sensitivity for elastography using scores 1 and 2 for benign and scores 3–5 for malignant lesions. The sensitivity was 71%, the specificity 48%, the ppv 39%, and the npv 78%. In the combination of BI-RADS descriptors and elastography, the sensitivity went up to 100% but the specificity dropped to 38% (ppv 39%, npv 100%). The observed different results obtained with comparable technologies may come from the investigator dependency of the elastography method.

This means that different tissue compression by different investigators with more or less strong pressure influences the elasticity image and the consecutive score. The position of a lesion (superficial or close to the chest wall in a voluminous breast) may also influence the elasticity result. The freehand technique does not offer an objective parameter to quantify the strain. The interobserver variability resulting from interpreting the same elastography images by 3 different readers is highlighted by Burnside et al. [42]. A significant interobserver variability was reported. For all 3 readers, the area under the receiver operating characteristic (ROC) curve was greater after B-mode image analysis and strain imaging compared to B-mode imaging alone. 2 readers had a significantly higher area under the ROC curve compared with the 3rd reader.

SWE with supersonic shear imaging on the one hand provides a color map presenting the shear wave propagation speed in meter per second (m/s). On the other hand, this technique offers an objective parameter (kPa) to quantify the tissue elasticity. Cysts with echogenic material (complicated cysts) can be differentiated from solid lesions because of their missing shear wave propagation [22]. Athanasiou et al. [22] published a BI-RADS B-mode imaging specificity of solid breast lesions of 63%. Combining the quantitative SWE with the BI-RADS evaluation, the overall specificity increased up to 96%. This means that, in this study, 46% of the BI-RADS 4 lesions could be down-staged to BI-RADS 3 by applying SWE. The B-mode imaging sensitivity without SWE was 96%, and combined 95%. At the Radiological Society of North America meeting 2010 (RSNA 2010), Cosgrove and colleagues presented data of a multicenter study on SWE with 1000 cases and an improvement of 20% on specificity compared with the BI-RADS classification alone. They showed an almost perfect agreement of the lesion size on SWE ($\kappa = 0.95$) and elasticity ($\kappa = 0.91$) calculated on 3 consecutive acquisitions. The area under the ROC curve for the BI-RADS assessment alone was 0.72. Adding SWE information to BI-

Table 1. 2D and 3D US combined with elastography: 8 steps presenting the modified diagnostic algorithm related to imaging technology and lesion analysis

	Imaging and analysis target	US technology
Step 1	lesion detection	2D US
Step 2	multidimensional lesion analysis (shape, orientation, margin, lesion boundary, echo pattern, posterior acoustic features, coronal plane pattern, calcifications)	3D US dataset
Step 3	lesion measurements and lesion volume calculation	3D US dataset of step 2
Step 4	documentation of the lesion with TUI or multiplanar display mode	3D US dataset of step 2
Step 5	vascular study of the lesion and surrounding tissue	2D or 3D US color dataset
Step 6	documentation of the lesion vascularity	2D or 3D US color dataset of step 5
Step 7	lesion elasticity – analysis and documentation	US elastography
Step 8	documentation of the lesion within the breast	2D panoramic scan

TUI = Tomographic ultrasound imaging.

RADS, the area under the ROC curve increased up to 0.89. They concluded that SWE is a reproducible technique that improves the US accuracy and is able to reduce unnecessary biopsies. Evans and colleagues, also at the RSNA 2010, presented a study of quantitative SWE focused on the cut-off value (kPa) between benign and malignant lesions. They selected the 50-kPa value to differentiate between benign and malignant lesions. Following this value, the statistical data on SWE showed a sensitivity of 97% (BI-RADS descriptors 87%), a specificity of 83% (BI-RADS descriptors 78%), a ppv of 88% (BI-RADS descriptors 84%), an npv of 95% (BI-RADS descriptors 82%), and an accuracy of 91% (BI-RADS descriptors 83%).

According to the wide range of US modalities discussed above, a time-saving diagnostic algorithm for an effective use of advanced 2D and 3D/4D US technologies was published by Weismann and Datz [43]. This algorithm has to be adapted to modern US elastography technology and follows the logical order of 8 different steps. 4D US is no longer included in this updated algorithm. These modified 8 steps are presented in table 1.

Conclusions

Modern 2D B-mode imaging is used as the basic US technique to detect and describe breast lesions. 3D US is a perfect tool to analyze the grey-scale characteristics (BI-RADS descriptors) of a lesion, to measure the longitudinal axes

perpendicular to each other and to calculate the volume of a lesion, to study the coronal plane and to document the lesion and the surrounding breast tissue. Complementary elastography displays the mechanical tissue properties and has the potential to enhance US specificity with maintained high US sensitivity. With all described elastography techniques, an overlap between benign and malignant lesions exists. Neither 4D grey-scale imaging nor 4D-VCI elastography have proven to enhance the true-positive or to reduce the false-positive results. As a consequence of this, 4D currently does not play a role in routine breast lesion assessment.

Summing up the discussion above, the answer to the question of this paper is: Elastography, especially on the highest standardized level with quantification of the tissue stiffness, is an important adjunct to 2D and 3D sonography. Elastography is not a stand-alone tool and does not replace 2D and 3D sonography.

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Disclosure Statement

The author and the coauthors declare that there are no conflicts of interest.

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