Automated Breast Ultrasound: Technical Aspects, Impact on Breast Screening, and Future Perspectives

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Abstract

Purpose of Review Automated breast ultrasound (ABUS) is a three-dimensional imaging technique, used as a supplemental screening tool in women with dense breasts. This review considers the technical aspects, pitfalls, and the use of ABUS in screening and clinical practice, together with new developments and future perspectives.

Recent Findings ABUS has been approved in the USA and Europe as a screening tool for asymptomatic women with dense breasts in addition to mammography. Supplemental US screening has high sensitivity for cancer detection, especially early-stage invasive cancers, and reduces the frequency of interval cancers. ABUS has similar diagnostic performance to handheld ultrasound (HHUS) and is designed to overcome the drawbacks of operator dependence and poor reproducibility. Concerns with ABUS, like HHUS, include relatively high recall rates and lengthy reading time when compared to mammography. ABUS is a new technique with unique features; therefore, adequate training is required to improve detection and reduce false positives. Computer-aided detection may reduce reading times and improve cancer detection. Other potential applications of ABUS include local staging, treatment response evaluation, breast density assessment, and integration of radiomics.

Summary ABUS provides an efficient, reproducible, and comprehensive supplemental imaging technique in breast screening. Developments with computer-aided detection may improve the sensitivity and specificity as well as radiologist confidence and reduce reading times, making this modality acceptable in large volume screening centers.

Keywords Automated breast ultrasound · Artifacts · Screening · Dense breasts

Introduction

Mammography is the primary modality used for breast cancer screening, with an estimated reduction in mortality of 20% [1]. Mammographic sensitivity drops to 61% in women with extremely dense breasts when compared to 86% in fatty breasts, leading to 6 times more interval cancers [2]. This is partially due to the "masking effect" caused by the overlapping fibroglandular tissue, resulting in delayed diagnosis, and larger cancers with often poorer prognosis [3]. Breast density also contributes to increased risk of breast cancer with a 4.6-fold increased risk for the densest group compared to the lowest density, fatty breasts[4].

Breast density can be measured using numerous methods and from images obtained on different modalities [5, 6]. Commonly, breast density is measured on digital mammography. Given its clinical importance, reader assigned (BI-RADS) and automated breast density measures (area and volume) have been included in the latest risk prediction models. The best measure of density to determine risk, when used alone or in combination with other risk models (Tyrer-Cuzick, BOADICEA, and Gail models), is yet to be determined [7–9]. Assessing density is important to target supplemental screening approaches for women with dense breasts.

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Various approaches and thresholds have been considered to guide the implementation of supplemental imaging, with studies evaluating which modality is best for this purpose [10, 11]. The BRAID multicenter UK trial is comparing automated breast ultrasound (ABUS), abbreviated magnetic resonance imaging (ABB MRI), and contrast-enhanced spectral mammography (CESM) as a supplemental screening tool [12].

Many studies support the use of the whole breast ultrasound as an appropriate supplemental screening tool in dense breasts, due to its accessibility, lack of intravenous (IV) contrast and ionizing radiation, and better patient tolerance [13–18]. Handheld ultrasound (HHUS) increases the cancer detection rate by 1.8–4.6 cancers per 1000 women screened, compared with mammography alone [14, 16, 19, 20]. However, the use of HHUS as a screening tool has its own disadvantages, i.e., radiologist time required to perform the examination, significant operator dependence, higher recall rates, and relatively low positive predictive value. Unlike handheld ultrasound (HHUS), automated breast ultrasound (ABUS) is a three-dimensional volume imaging technique, offering proper orientation and documentation, leading to better reproducibility and making it easier to compare with subsequent follow-up studies. It can be performed independently and in a more standardized way with trained radiographers, saving radiologist time and improving efficiency [21].

Technical Aspects

The use of ABUS for breast cancer screening was introduced in 1980 [13], to deal with the shortcomings of mammography [22] in detecting cancer in women with dense breasts.

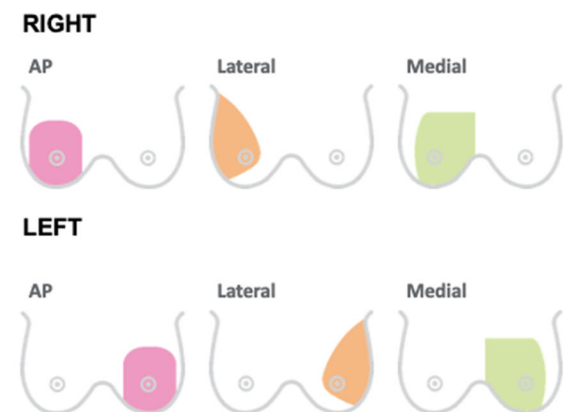ABUS systems are available in two categories: supine [23, 24] and prone [25, 26]. The latest supine 3D ABUS devices consist of an articulated arm with a long transducer, a touchscreen monitor, and a dedicated workstation for image interpretation. The transducers are automatically adjusted over their frequency range (~5–15 MHz), according to the chosen depth, producing 3D datasets with hundreds of images per acquisition at slice intervals of ~2 mm without overlap. Technical advances of 3D ABUS systems consist in special software that enables optimized quality images with high resolution and uniformity throughout the image due to advanced reconstruction algorithms and automated adjustment of settings such as frequency, time gain compensation, harmonics, nipple shadow, and speckle reduction imaging [22].

A standard ABUS protocol consists of scanning each breast separately in three planes, anterior-posterior (AP), lateral (LAT), and medial (MED) positions, resulting in six images for both breasts. Additional views may be required in women with larger breasts to cover the whole area with four images (two per each breast) sufficient in smaller breasts (Fig. 1). Adequate patient positioning, transducer placement, proper depth selection, and compression are crucial in acquiring high-quality images with the total examination, including patient preparation, lasting approximately 15–20 min. Regular quality assurance tests should be performed as for ultrasound equipment. The volume data is processed automatically in multiplanar reconstruction (coronal and sagittal planes) and is transferred to a dedicated workstation for interpretation as full, reconstructed image sets cannot yet be viewed on picture archiving and communication system (PACS) workstations as standard.
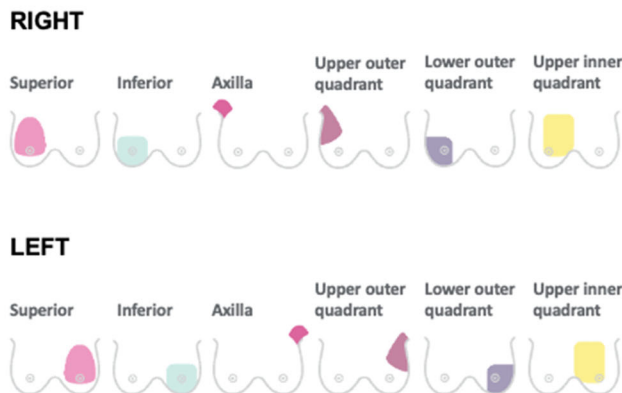
Artifacts and Pitfalls

In a retrospective analysis of 1890 ABUS studies, the most common reasons for false-negative readings on ABUS exams

Fig 1 Overview of the ABUS scanning views with 3 standard views for each breast and 6 optional views based on patient body habitus, image used with kind permission from GE Healthcare

were reported as poor visibility, peripheral lesion location, and shadowing obscuring the lesion [27].

Technical artifacts such as loss-of-contact, dropout artifacts due to poor scanning or skin folding are the most common cause of poor visibility. Adequate patient positioning, uniform amount of lotion, and appropriate transducer placement and compression should be ensured to avoid this type of artifacts, while documenting skin lesions such as moles and surgical scars is also recommended (Fig. 2a). *Nipple shadowing* is another artifact, more commonly seen in inverted nipples; however, applying an abundance of water-based lotion in this area as well as integrated software algorithms, such as tissue equalization algorithm and nipple shadow compensation, helps in reducing this type of artifact [21]. Hyperventilation, tachycardia, coughing, and talking are the common *physiological conditions–related artifacts*. Their repetitive sinusoidal wave pattern makes them easy to detect [21, 28]; they are more prominent near the chest wall and can distort the deeper regions of the coronal and sagittal reformations. *Breast lesion–related artifacts* such as skip artifact and white wall sign are unique to ABUS and can assist in diagnosis/differentiation of specific lesions [28]. A *skip artifact* is caused when the transducer encounters a firm mass and presents as an artifactual horizontal line on the coronal plane (Fig. 2b); these may also occur due to prominent ribs. *White wall signs* are seen as hypoechoic circumscribed areas before a cyst in the coronal plane and are equivalent to the posterior enhancement in HHUS (Fig. 2c); their appearance is a typical sign of benign lesions [21].

Shadowing artifacts: This type of artifact is one of the major challenges in ABUS interpretation. It is crucial to distinguish between shadowing originating from normal breast parenchyma and those from true lesions due to their high correlation with malignant masses. "Wandering shadows" caused by the interference of ultrasound waves with curved surfaces of Cooper ligaments, presenting as repetitive linear shadows in the transverse plane (Fig. 2d), are common in ABUS examinations [21]. They tend to be more prominent in heterogeneous dense breasts, on the lateral and medial planes, and the periphery, potentially leading to misinterpretation [27]. Uniform compression and proper positioning are essential in reducing this type of artifact [22]. In a recent study, shadowing was classified in four categories, and a methodical approach was suggested to minimize false positives [28]. The persistence of an apparent lesion in more than one plane (axial and coronal/sagittal) is a strong positive finding that needs to be recalled. Sagittal plane might be helpful in certain cases to rule out true lesions (Fig. 2d).

ABUS Implementations in a Screening Setting

Many studies indicate that ABUS is a good supplemental screening tool for women with dense breasts, with a diagnostic performance similar to screening HHUS [29] and an increase of cancer detection rate by 1.9–7.7 cases per 1000 women compared to mammography alone [23, 30–33]. Sensitivity increased with 21.6–41.0%, but specificity varied.
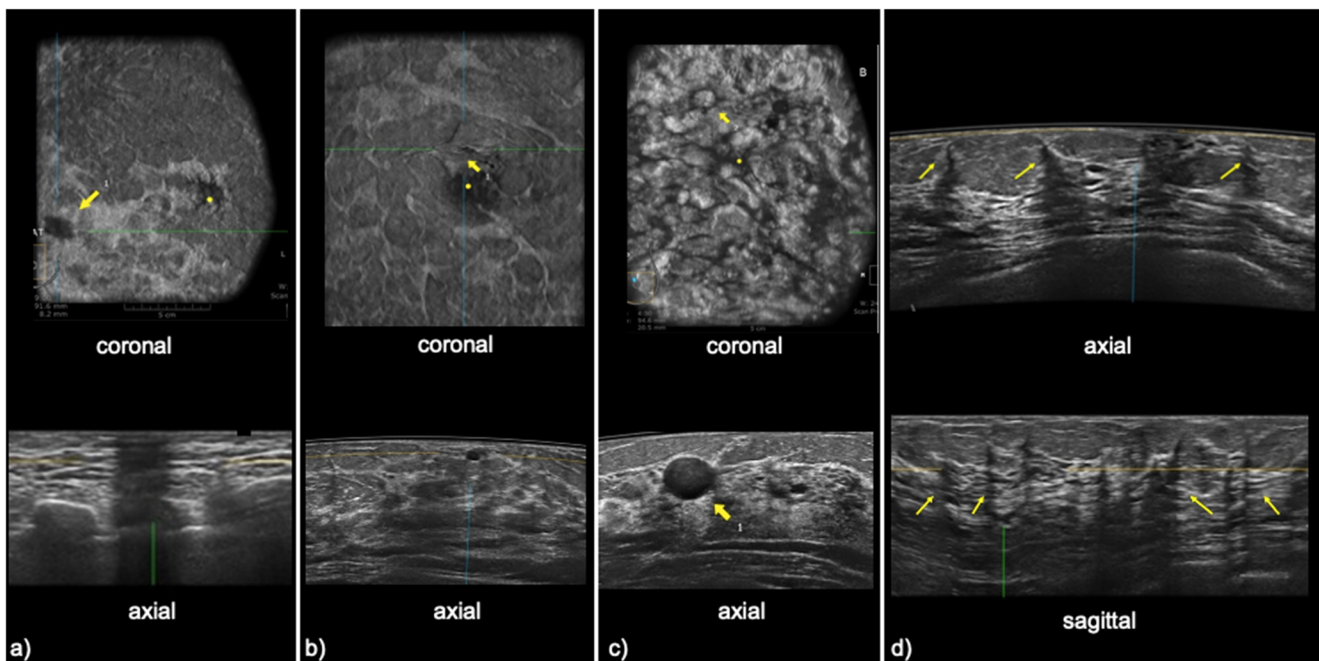
Fig. 2 Artifacts from ABUS (**a**) Contact artifact from a mole on both the coronal and saggital plane, shown by arrows. (**b**) Skip artifact from cyst on both the coronal and axial images. (**c**) White wall sign ; round echogenic area in coronal images, corresponding to the posterior enhancement of cyst in axial plane, shown by arrows (**d**) Wandering Shadows ; linear repetitive shadows in axial and sagittal planes, shown by arrows

In the largest ABUS study (SomoInsight Study) of 15,318 women with dense breasts, the cancer detection rate was reported as 1.9 cases per 1000 women [23], similar to the results of Japan Strategic Anti-cancer Randomized Trial (J-START) [18] but lower than the results of American College of Radiology Imaging Network 6666 [16]; this difference was due to the different inclusion criteria of these studies. Most of the cancers detected were small, invasive, and predominantly node negative (Table 1).

Recall and biopsy rates tend to increase with ABUS as well (Table 1). These values have improved recently, due to increased reader experience and software developments with the latest ABUS systems [35, 36]. This new modality has a learning curve, so adequate training and state-of-the-art examinations along with integration of computer-aided detection (CAD) software will potentially improve accuracy and reduce recall rates [37].

Recent European Society of Breast Imaging (EUSOBI) guidelines recommend the usage of HHUS or 3D ABUS as a supplemental screening modality following a negative mammogram in women of average or intermediate risk with dense breasts, C and D, according to Breast Imaging Reporting and Data System (BI-RADS) Atlas, 5th edition [38, 39]. In addition, screening ABUS can be offered as an alternative to MRI in high-risk women in limited facilities or when MRI is contraindicated [11]. Incremental cancer detection rates are higher, between 2 and 3.6 per 1000 screens, for ABUS in comparison to digital breast tomosynthesis (DBT) (1–2 per 1000 screens) when used as a supplemental screening tool in women with dense breasts. These values are similar to HHUS but significantly lower than MRI and CESM. However, this comes at the expense of IV contrast administration, ionizing radiation, and higher recall rates [29]. In addition, MRI is not as widely accessible and requires more specialized training. Large multicentric randomized trials with long-term follow-up are needed to assess the feasibility of ABUS as an additional screening tool in reducing mortality rates [22].

Computer-Aided Detection/Diagnosis

A drawback of ABUS is the relatively long interpretation time due to a larger volume of images to be analyzed in both coronal and axial planes. The reading time reported so far varies significantly (2.9–9 min), attributable to variation in radiologists' experience and complexity of cases [23, 29, 31, 40]. A CAD software for 3D ABUS (QVCAD™, QView Medical) has been recently developed and FDA approved [41]. Several studies have been investigating the benefits of concurrent-read CAD systems for interpretation of screening ABUS, and CAD seems to significantly reduce interpretation time, up to 35%, as well as improving diagnostic accuracy [42–44]. Another approach to speed up reading is the use of coronal plane only [45], but more work on this is required to ensure that sensitivity does not drop. Further work is required to evaluate the feasibility of CAD in a screening setting.

In the ASSURE project, 120 unilateral ABUS exams chosen randomly were analyzed by eight experienced breast radiologists using CAD software. The reading time was significantly reduced by 15% overall [46]. CAD discarded 42.6% of BI-RADS ≥3 lesions, 85.5% of which were benign, suggesting that CAD software could improve accuracy and potentially reduce unnecessary recalls [47].

ABUS Implementations in Clinical Setting

Symptomatic Breast Imaging

ABUS use in clinical practice is still under investigation. Several studies have reported similar diagnostic performance of ABUS to HHUS in differentiation of benign and malignant lesions (Table 2). In a recent meta-analysis of nine studies involving 1527 lesions, ABUS was found to have higher pooled sensitivity (93%) and specificity (86%) in detecting lesions,

Table 1 Results from 4 major studies examining supplemental screening with ultrasound [33, 34]

Study	SomoInsight (Brem 2015) [23]	Wilczek (2016) [31]	ACRIN 6666 (Berg 2012) [16]	J- START (Ohuchi 2016) [18]
Modality	ABUS	ABUS	HHUS	HHUS
Study population	Asymptomatic women with dense breasts (15,318)	Asymptomatic women with dense breasts (1668)	Asymptomatic women at high risk (2809)	Asymptomatic women in their 40s (36,752)
Cancer detection (rate per 1000)	1.9	2.4	5.3	1.8
Net added recalls per screen (%)	13.5	0.9	7.4	5.4
Invasive cancers (%)	93.3	NR	93.7	82.0
Mean size of cancers (mm)	12.9	21.8	10.0	14.2
Node negative cancers (%)	92.6	50.0	96.7	85.5

Table 2 Major studies comparing sensitivity and specificity of ABUS (automatic breast ultrasound) and HHUS (handheld ultrasound) in clinical practice [48, 49]

Study	Patients number	Sensitivity %		Specificity %	
		ABUS	US	ABUS	US
Cho et al. [50]	141	98.3	96.7	96.7	64.4
Kotsianos-Hermle et al. [51]	97	95	97	93	88
Wang HY et al. [52]	213	95.3	90.6	80.5	82.5
Wang ZL et al. [53]	155	96.1	93.2	91.9	88,7
Chen et al. [54]	175	92.5	88.1	86.2	87.5
Jeh et al. [55]	173	88	95.7	76.2	49.4
Niu et al. [56]	398	92.23	82.52	77.62	80.24

compared to HHUS (90% and 82%, respectively) [48]. However, these are small studies with relatively low number of lesions. Looking at interobserver reliability in BI-RADS assessment, heterogeneous results with considerable variation in kappa values have been reported [57]. Vourtsis and Katchulis found a very high (99.8 %; kappa = 0.994, p < 0.0001) interobserver agreement in BI-RADS classification between 3D ABUS and HHUS, in a retrospective study of 1886 women, with ABUS superiority in detecting architectural distortion [29]. Another recently published multicentric study of 937 Chinese women with dense breasts, evaluating the diagnostic performance of ABUS and HHUS in combination with mammography, reported significant improvement in cancer detection rate as well as strong correlation between ABUS and HHUS, with an accuracy of 93% for ABUS and 92% for HHUS and 94% agreement between them [58].

The coronal plane is a specific feature of ABUS that enables the visualization of a lesion in the anatomical plane and contributes to better detection and characterization [59, 60]. One of the unique findings of coronal plane is the so-called retraction phenomenon, frequently a sign of architectural distortion and malignancy (Fig. 3) that can supplement mammography in detecting noncalcified carcinomas in women with dense breasts [29]. Zheng et al. reported that the retraction sign and microlobulated margins have both high diagnostic values in distinguishing between benign and malignant breast masses in ABUS [60].

A recent study analyzing 457 lesions in coronal plane, including 80 non-mass lesions, concluded that the retraction phenomenon is highly predictive of malignancy; continuous hyper- or hypoechoic rims were more associated with benign lesions, whereas discontinuous rims were suggestive of malignancies. For the non-mass lesions, the skip artifact was found to correlate more with malignant lesions [61]. In addition, ABUS

seems to outperform HHUS in volumetric measurements of lesions, with significant higher accuracy [62, 63].

Local Staging Breast magnetic resonance imaging (MRI) is the gold standard in the evaluation of disease extent and treatment planning. 3D ABUS could be a good alternative to MRI in finding additional lesions due to its three-dimensional orientation and repeatability (Fig. 3). In a recent study comparing the diagnostic value of ABUS to HHUS with MRI as gold standard, they reported similar diagnostic accuracy for ABUS and HHUS (87.2% and 89.7%) but better size correlation between ABUS and MRI (r = 0.89) compared to HHUS (r = 0.82) [64]. In a similar study including 100 index cancers, ABUS showed better agreement with histology than HHUS with a higher intraclass correlation (ICC), 0.85 vs 0.75, respectively [65]. Furthermore, the coronal plane provides better segmental approach, and global visualization of the tumor with similar surgical orientation therefore might be useful in surgical planning (Fig. 4). In another analysis of 142 biopsy-proven DCIS cases examining the use of ABUS in guiding breast conservation surgery, ABUS was superior to HHUS in both surgery planning and predicting recurrence, with a detection rate significantly higher (χ^2 = 268.000, P < 0.001) [63]. Semiautomated and automated algorithms for ABUS lesion segmentation and volume measuring are under investigation [66, 67].

Monitoring Response to Neoadjuvant Chemotherapy US can be a potentially useful imaging modality for early prediction of pathological response to NAC [68]. ABUS is a promising tool, offering better orientation and reproducibility in comparison to HHUS. In a recent study, Wang et al. reported high sensitivity (88.1%) and specificity (81.5%) of ABUS coronal plane, in predicting pathological complete response (pCR) rate after four cycles of chemotherapy [69]. They concluded that

Fig. 3 A multifical grade II invasive carcinoma of no special type (NST) with intratumoral low grade DCIS, presenting with (**a**) "The retraction sign" (circle) and two foci of tumour, 18 mm and 6 mm (arrows) on ABUS coronal plane and (**b**) corresponding HHUS images
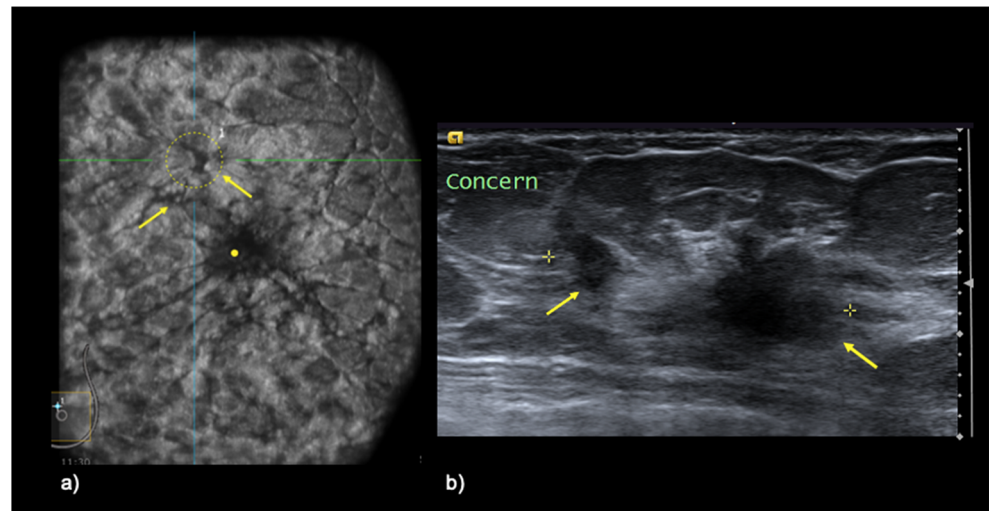

ABUS is a useful tool in early evaluation of pathological complete response after 2 cycles of NAC while less reliable when predicting poor pathological outcomes.

Second-look ABUS Another potential application of ABUS is the further evaluation of MRI findings instead of second-look HHUS. Recent studies have shown that ABUS is better than HHUS and with similar performance to MRI in predicting breast cancer size and finding additional lesions [65, 70, 71]. Therefore, it can be a good alternative to MRI in guiding breast conservation surgery and predicting recurrence [63].

However, there are some limitations of ABUS such as lack of image-guided biopsy and axilla and tumor vascularity assessment.

Fig. 4 Irregular 9 mm hypoechoic lesion on ABUS (**a**) coronal and (**b**) axial planes (circle) ,corresponding (**c**) postcontrast MRI and (**d**) second-look US images (arrows). Unifocal Invasive Lobular Carcinoma with very good correlation of lesion size and location between MRI and ABUS
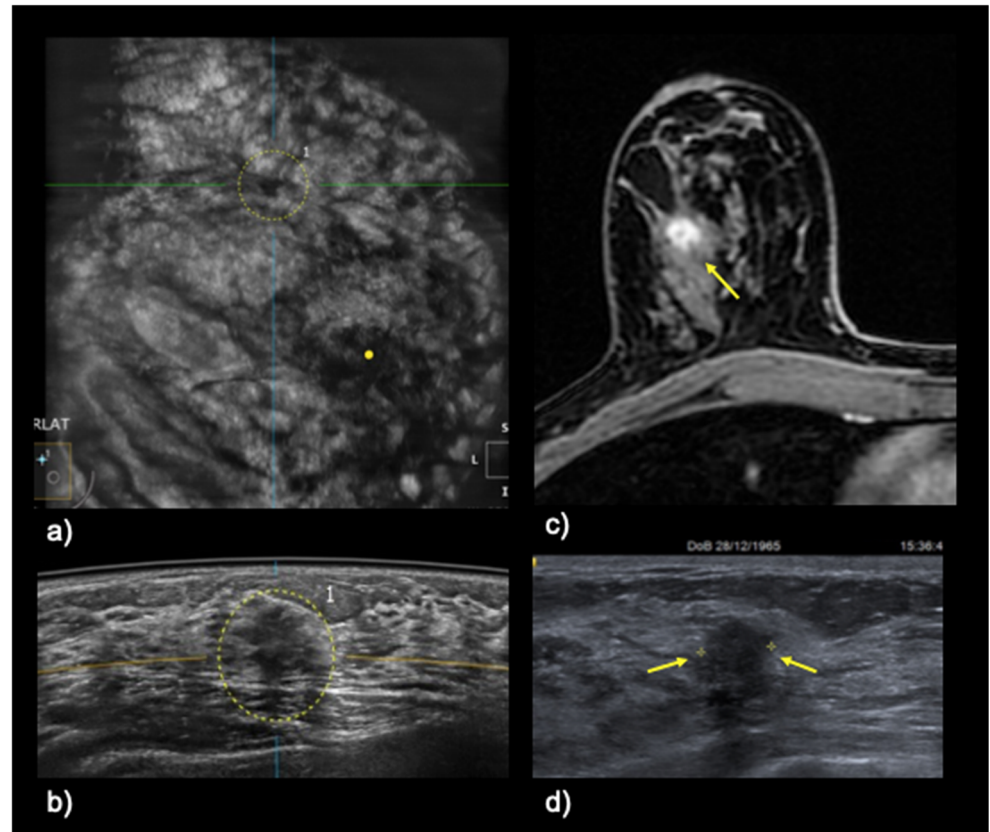
Future Perspectives

Ongoing research is looking at correlation between molecular subtypes of breast cancer and ABUS morphological features. In a recent analysis of 303 malignant lesions, strong correlation was found between their specific imaging features on ABUS such as retraction, post-acoustic shadowing, echogenic halo, calcifications, and molecular subtypes, especially for the "retraction phenomenon" on coronal views, as the strongest independent predictor for the luminal-A subtype when present and for the triple-negative subtype when absent [72].

Other possible implementations of ABUS include breast density evaluation [54, 73]. In their study, Chen et al. found a high correlation of density results between MRI and ABUS, for whole breast volume (r = 0.798) and for breast percentage density (r = 0.825) [74].

ABUS can be used for follow-up of benign lesions, due to its precise documentation and orientation. In a retrospective study evaluating the reproducibility of ABUS, readers ICCs for lesion location (clock face location, distance from nipple) and size were reported as 0.994, 0.926, and 0.980, respectively, suggesting high reliability [75].

Fusion-X-US is a new device under investigation, combining ABUS and tomosynthesis in one device, aiming to improve workflow in clinical practice. Preliminary results of a prospective study, analyzing 101 patients with this prototype, showed good breast coverage (80.0%) and diagnostic accuracy of ABUS (85.0%), as well as 97.1% lesion identification with the combined system [76].

Conclusions

ABUS is a good supplemental screening tool for women with dense breasts and should be considered as an alternative to other modalities due to good patient tolerance, lack of ionizing radiation, and IV contrast. CAD is a promising tool in reducing interpretation time and improving ABUS accuracy. Other possible applications include use in symptomatic clinics in younger women and for surveillance of benign lesions, local staging, monitoring response to NAC, second-look tool, correlation with molecular subtypes of breast cancer, and breast density evaluation. Further developments are expected in the field of deep learning and integration of radiomics. Larger studies, robust training, and software incorporation and standardization are required for better implementation of this imaging modality in screening and diagnostic setting.

Availability of Data and Materials Not applicable

Code Availability Not applicable

Competing Interests I Allajbeu: no conflict of interest to disclose
S Hickman: has research collaborations with Merantix, ScreenPoint, Volpara, and Lunit
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Author Contribution All authors have made substantial contribution to the design of this article, review and interpretation of the relevant literature, as well as providing critical feedback according to their field of expertise.

Declarations

Ethics Approval Not applicable

Consent to Particip0061te Not applicable

Consent for Publication Yes

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