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Comparison of automated breast volume scanning to hand-held ultrasound and mammography

Confronto tra scansione ecografica automatica del volume mammario, ecografia convenzionale e mammografia

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Abstract
Purpose. Our aim was to investigate the diagnostic potential of automated breast volume scanning (ABVS) and compare it with manual ultrasound (US) and mammography.
Patients and methods. One hundred and fifty-five patients with a total of 165 breast lesions had mammograms, manual US and an ABVS. Multiplanar reconstructions in coronal, transverse and sagittal views were reconstructed from the automated data set. After biopsy or surgery, all lesions were confirmed histologically. Data were evaluated according to the Breast Imaging Reporting and Data System (BI-RADS) classification. Detection rate, diagnostic accuracy, sensitivity, specificity and positive (PPV) and negative (NPV) predictive value of each method were analysed.
Results. Detection rate, diagnostic accuracy and mammography sensitivity were significantly lower than those of each US method ($p<0.05$). There were no significant differences between manual US and ABVS. When combining ABVS, US and mammography, diagnostic accuracy, sensitivity and specificity reached 96.4%, 97.1% and 95.2%, respectively. A spiculated and stellate margin in the coronal plane has a high specificity in diagnosing malignant lesions.
Conclusions. ABVS can provide additional information in the differential diagnosis of a lesion. It has significantly higher sensitivity than mammography, but it is similar to manual US and cannot be preferred to a manual US examination.

Keywords 3D ultrasound · Breast lesions · BI-RADS · Mammography · Multiplanar reconstructions

Riassunto
Obiettivo. *Valutare le potenzialità diagnostiche della scansione automatica del volume del seno (ABVS) nei confronti dell'ecografia convenzionale (US) e della mammografia.*
Pazienti e metodi. *155 pazienti con un totale di 165 lesioni mammarie sono state studiate con mammografia, ecografia convenzionale e scansione automatica del volume mammario (ABVS). Dal volume dei dati acquisiti in modo automatico sono state realizzate ricostruzioni multiplanari nei piani coronale, assiale e sagittale. Tutte le lesioni sono state confermate istologicamente. I dati sono stati valutati secondo la classificazione BI-RADS (Breast Imaging Reporting e Data System). Per ciascuna modalità sono stati analizzati il tasso di rilevamento, l'accuratezza diagnostica, la sensibilità, la specificità, il valore predittivo positivo (VPP) ed il valore predittivo negativo (VPN).*
Risultati. *Il tasso di rilevamento, l'accuratezza diagnostica e la sensibilità della mammografia erano significativamente inferiori a quelli di ciascun metodo ecografico ($p<0,05$). Non si sono evidenziate differenze statisticamente significative tra l'ecografia convenzionale e l'ABVS. Quando si combinano l'ABVS, l'ecografia convenzionale e la mammografia, l'accuratezza diagnostica, la sensibilità e la specificità raggiungono il 96,4%, il 97,1% e il 95,2%, rispettivamente. I margini spiculati e stellati nel piano coronale hanno una elevata specificità nella diagnosi di lesioni maligne.*
Conclusioni. *L'ABVS può fornire ulteriori informazioni nella diagnosi differenziale di una lesione. Esso ha*

una sensibilità significativamente maggiore della mammografia, ma è simile all'ecografia convenzionale e non può essere preferibile ad un esame ecografico convenzionale.

Parole chiave *Ecografia 3D · Lesioni mammarie · BI-RADS · Mammografia · Ricostruzioni multiplanari*

Introduction

In manual ultrasound (US), a breast lesion has to be immediately characterised during the examination. Because US is operator dependent and nonreproducible, the hand-held technique is seldom used at its full capacity in breast cancer evaluation. Moreover, a shortcoming of manual US is that it cannot display the breast lesion in the coronal plane. Three-dimensional US breast imaging could provide a third look at the breast in the coronal direction, allowing visualisation of multiplanar reconstructions in three planes. Three-dimensional (3D) US has shown promise in the obstetric, gynaecological, prostate, breast and cardiovascular fields [1–5]. It can display anatomical and pathological features in planes not possible with conventional 2D US [2]. By using 3D US, complex growth patterns and their margins can be better appreciated in three orthogonal planes in both benign and malignant tumours.

Automated breast volume scanning (ABVS) a 3D function performed with an ACUSON S2000 ultrasound system and ABVS attachment. It features an adjustable scanner arm and automated one-button pressure and locking mechanism to improve workflow by simplifying and expediting volume acquisition for consistent results.

Few studies have assessed the application of ABVS to the diagnosis of breast lesions [6, 7], and the main purpose of these studies was to compare ABVS with manual US. The aim of this study was to compare the diagnostic efficiency of ABVS with those of manual US and mammography in the differentiation of benign from malignant solid breast masses, with histopathologic examination as the reference standard.

Patients and methods

From May 2010 to August 2010, mammography, manual US and ABVS were performed in 155 consecutive patients (total 165 lesions) scheduled to undergo US-guided core needle biopsy due to suspicious breast lesions detected during screening mammography or manual US. Patients' age range was 23–65 (mean age±standard deviation, 43.1±21.2) years. The study was approved by our local ethics committee, and written informed consent was obtained from every patient at enrolment.

Pathologic results were available for all lesions. According to the American College of Radiology (ACR) Breast Imaging Reporting and Data System (BI-RADS) [8, 9], final assessment of the lesions on the basis of both mammographic and US findings before biopsy was category 3 (probably benign) for 62 lesions (37.6%); category 4 (suspicious) for 31 (18.8%); and category 5 (highly suggestive of malignancy) for 72 (43.6%). Biopsy was performed in the 62 probably benign lesions because of patient or referring clinician preference on clinical grounds.

Lesion diameter at histopathological examination was 5–36 mm (mean ± standard deviation, 16.7±10.5 mm). All lesions were confirmed with pathology after surgical excision (n=112) or with US-guided percutaneous core needle biopsy (n=53) within 48 h of US examination. Surgical excision was performed in 92 lesions because of suspicious or malignant findings at a previous percutaneous core needle biopsy (n = 76) and referring clinician preference on clinical grounds (n=16).

Mammography and manual ultrasound

Mammograms were taken with a Senograph 2000 (GE Healthcare, Waukesha, WI, USA) in craniocaudal (27 kV, 85 mAs, Mo/Mo) and mediolateral–oblique views (27 kV, 58 mAs, Mo/Mo). Breast density was according to BI-RADS categories and/or quantification: ACR 1, almost entirely fat (low density, up to 25% mammary gland parenchyma); ACR 2, scattered fibroglandular densities (average density, 26–50% gland parenchyma); ACR 3, heterogeneously dense (high density, 51–75% gland parenchyma); ACR 4, extremely dense (very high density, >75% gland parenchyma) [10].

A manual US examination was performed with an ACUSON S2000 US system (Acuson, Mountain View, CA, USA) with a 14L-5 linear-array probe, and iU22 US system (Philips Medical Systems, Andover, MA< USA) with a L12-5 linear-array probe by one radiologist (ZLW) with 10 years of experience in breast US. The breast was examined in overlapping antiradial scans (perpendicular to the ducts) and duct parallel (mamilloradial). With the patient supine,

suspect regions were imaged in two perpendicular scanning planes (sagittal and transverse), and Data Imaging and Communications in Medicine (DICOM) images were stored on hard disks. After the manual US examination, ABVS was done according to the procedure described below.

Automated breast volume scanning (ABVS)

Automated breast US was performed using an ACUSON S2000 system with the ABVS attachment. Workflow is streamlined with image presets optimised to the patient's cup size. The system automatically adjusts depth, frequency, focal zone placement and overall gain.

A typical examination comprises three automated 65-s scans of each breast in the anteroposterior (AP) and both oblique positions. Occasional additional views are required for larger breasts, with scans centred on a palpable abnormality or axillary lymph nodes. The large-footprint wide-frequency bandwidth transducer uses a high centre frequency. This 14L-5BV transducer captures a volume of up to 15.4 cm×16.8 cm×6 cm by acquiring a series of 320 high-resolution transverse 2D images at slice intervals of 0.5 mm. Real-time Advanced SieClear spatial compounding is employed in combination with Dynamic tetrachlorodiphenylethane (TCE) tissue contrast-enhancement technology during the scanning process. After the acquisition is finished, proprietary postprocessing algorithms are applied based on nipple location to maximise diagnostic information quality.

After acquisition, the transverse image series is automatically sent from the ACUSON S2000 ABVS to a dedicated breast US review workstation that presents images through multiplanar reconstruction (MPR) and reconstructs secondary images from the acquisition volume in any plane, such as sagittal, coronal, radial and antiradial views. The workstation is used for comprehensive analysis, interpretation and manipulation of the acquired 2D and 3D data. Figure 1 shows an example of the three multiplanar compounded reconstructions from ABVS in comparison with the mammogram.

Data evaluation

The acquired DICOM data were analysed offline at a separate workstation and evaluated by two radiologists (LG, XN) with 5 and 6 years, respectively in mammography. Image data from the manual US were evaluated by two radiologists (WZL, WWB) with 12 and 15 years, respectively, in US. Image data from the automated US were evaluated by two radiologists (HY LJL), blinded to mammographic and US findings, with 6 months' experience each in automated US.

Results were documented on a standard form during image analysis. Breast tissue density was classified according to their criteria from ACR 1– 4, and patient age was analysed. After completing the reading session and receiving histopathological results, diagnostic accuracy, sensitivity, specificity and positive (PPV) and negative (NPV) predictive values were calculated for each method.

Statistical analysis

All analyses were performed using SPSS11.0, standard version (SPSS Inc, Chicago, IL, USA). BI-RADS variabilities in reader final assessment categories were calculated for manual US, ABVS and mammography with κ statistics. A κ value ≤0.20 was considered slight; 0.21–0.40, fair; 0.41–0.60, moderate; 0.61–0.80, substantial; and 0.81– 1.00, almost perfect [11]. Accuracy, sensitivity, specificity, PPV and NPV were calculated for mammography and manual and automated US. BI-RADS classes 1–3 were combined and rated as benign; classes 4–5 were also combined and rated as malignant. Comparison among groups was done using the χ^2 test. $p<0.05$ was considered statistically significant.

Results

Of the 165 lesions, histopathological diagnosis comprised 81 invasive ductal carcinoma (IDC), 18 ductal carcinoma in situ (DCIS), four invasive lobular carcinoma, eight intraductal papillomas, 34 fibroadenomas, 17 adenosis and three mastopathic changes. The distribution of breast tissue density according to ACR was analysed: ACR 1 in 7.3% (12/165) of the patients, ACR 2 in 20.0% (33/165), ACR 3 in 44.2% (73/165) and ACR 4 in 28.5% (47/165).

Reader agreement

Interobserver agreement between the two radiologists for the final assessment of solid breast masses was similar for manual US images (κ=0.418±0.209), for ABVS (κ=0.443±0.203) and for mammography (κ=0.425±0.208) ($p>0.05$).

Lesion detection

Mammography detected 145 lesions, and lesions were observed as a mass in 85 instances, a mass with calcification in 39, focal asymmetry in 13, clustered microcalcification in four and architectural distortion in four. Manual US and ABVS detected 158 and 161 lesions, respectively. Lesion detection rates of manual US, ABVS and mammography were 95.8% (158/165), 97.6% (161/165) and 87.8% (145/165), respectively. US and ABVS detection rates were significantly higher than that of mammography ($p<0.05$).

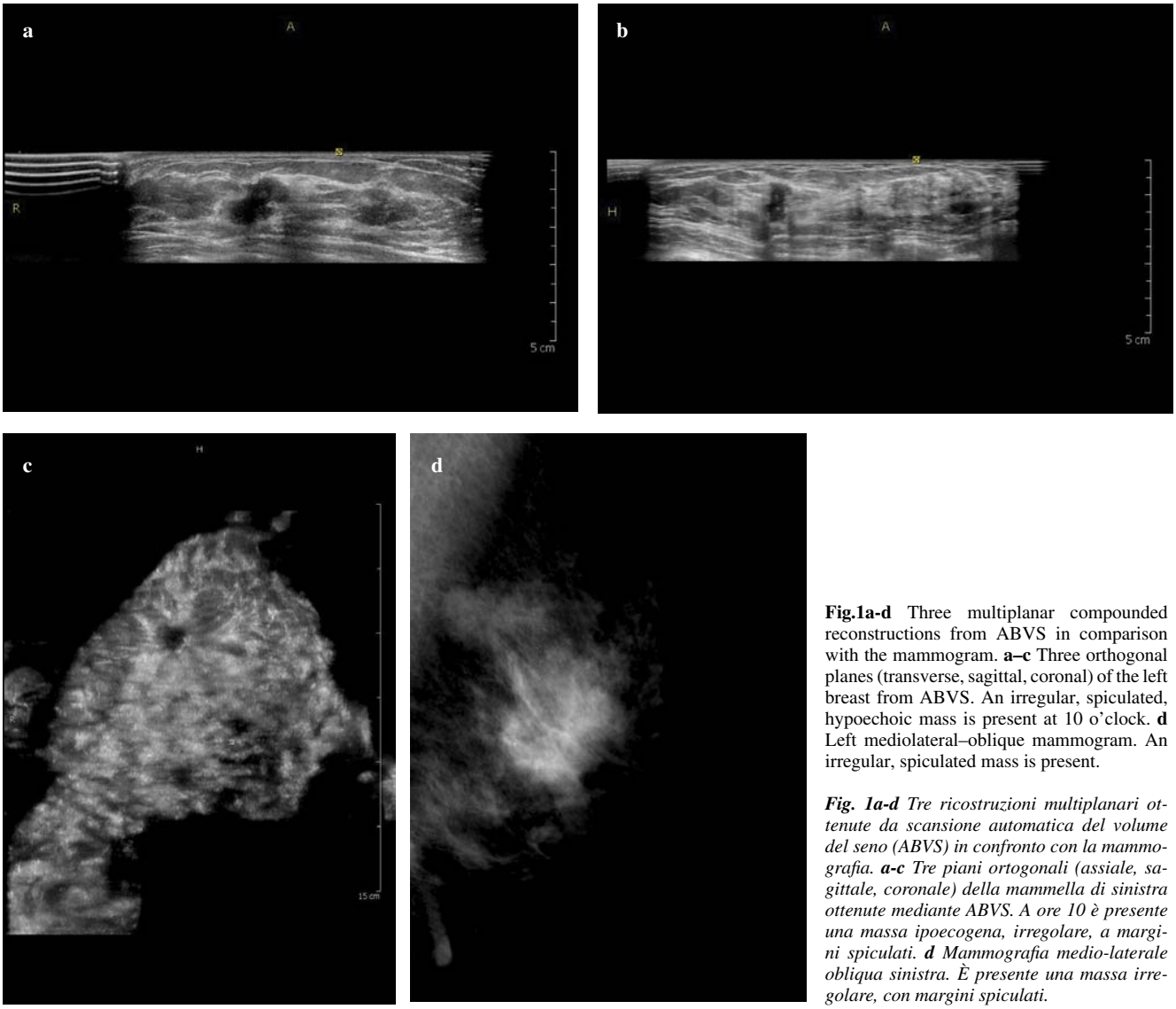

Fig.1a-d Three multiplanar compounded reconstructions from ABVS in comparison with the mammogram. **a–c** Three orthogonal planes (transverse, sagittal, coronal) of the left breast from ABVS. An irregular, spiculated, hypoechoic mass is present at 10 o'clock. **d** Left mediolateral–oblique mammogram. An irregular, spiculated mass is present.

Fig. 1a-d *Tre ricostruzioni multiplanari ottenute da scansione automatica del volume del seno (ABVS) in confronto con la mammografia.* ***a-c*** *Tre piani ortogonali (assiale, sagittale, coronale) della mammella di sinistra ottenute mediante ABVS. A ore 10 è presente una massa ipoecogena, irregolare, a margini spiculati.* ***d*** *Mammografia medio-laterale obliqua sinistra. È presente una massa irregolare, con margini spiculati.*

In the 20 lesions undetected by mammograms, eight were malignant and 12 were benign. All 20 lesions were detected by US and ABVS, and all were in breasts with a higher tissue density (ACR 3–4). Of the four lesions undetected by ABVS, one was malignant and three benign. The malignant lesion was a clustered microcalcification. Of the seven undetected by US, two were malignant and five were benign. The two malignant lesions were clustered microcalcifications.

Diagnostic accuracy, sensitivity, specificity, PPV and NPV

Results are listed in Table 1. No benign lesion was classified as BI-RADS 5 with ABVS, US or mammography. ABVS

Table 1 Accuracy, sensitivity, specificity and positive (PPV) and negative (NPV) predictive value of the different imaging methods

Tabella 1 *Accuratezza, sensibilità e specificità, valore predittivo positivo (PPV) e valore predittivo negativo (NPV) delle diverse modalità di immagine*

	Accuracy (%)	Sensitivity (%)	Specificity (%)	PPV	NPV
US	91.5	93.2	88.7	93.2	88.7
ABVS	94.5	96.1	91.9	95.2	93.4
Mammography	86.1*	83.5*	90.3	93.5	76.7

* Compared with the other methods, $p<0.05$

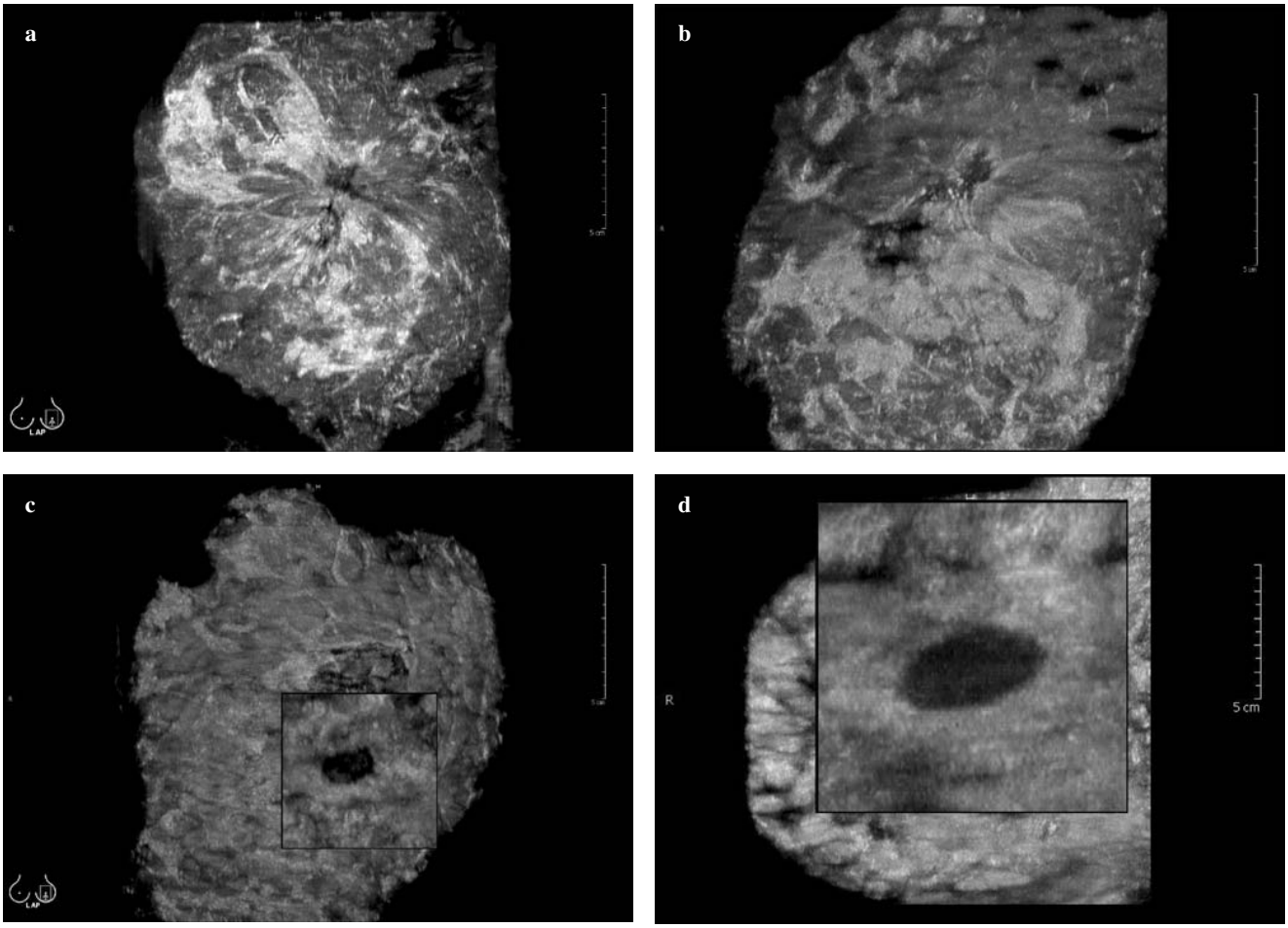

Fig. 2a-d Four different lesions in the ABVS coronal plane. **a,b** Two invasive ductal carcinomas are seen as stellate lesions with disruption of the surrounding breast tissue. **c,d** Two fibroadenomas show circumscribed margins, with no disruption of the surrounding tissue.

Fig. 2a-d *Quattro differenti lesioni nel piano coronale ottenute mediante ABVS.* ***a,b*** *Due esempi di carcinomi duttali invasivi caratterizzati da aspetto stellato con infiltrazione del tessuto mammario circostante.* ***c,d*** *Due esempi di fibroadenomi che presentano margini ben definiti, senza segni di infiltrazione del tessuto mammario circostante.*

was the same or better than manual US in terms of accuracy, sensitivity, specificity, PPV and NPV. Differences were not statistically significant ($p>0.05$). However, both manual US and ABVS had a significantly better accuracy and sensitivity than mammography ($p<0.05$). With combined US, ABVS and mammography, diagnostic accuracy, sensitivity and specificity reached 96.4%, 97.1% and 95.2%, respectively.

Value of coronal plane in 3D ultrasound

As the coronal plane is unique to the 3D technique and not available for conventional manual US, it is important to emphasise the role of the coronal plane in the diagnosis. On coronal images, 67.7% (42/62) of benign tumours were surrounded by a continuous hyperechoic rim. The spiculated and stellate margin of the breast cancer was best appreciated on coronal images (Fig. 2). Of the103 malignant tumours detected by ABVS, 61 had stellate margins. The stellate margin had a high specificity (98.4%) but a low sensitivity (57.5%), with an accuracy to determine malignant and benign lesions of 73.9%; PPV and NPV were 98.4% and 59.2%, respectively.

Discussion

All patients had breast lesions and differed in age from a typical screening population. Mean patient age was 43.1 21.2 years, whereas patients in screening series are typically >50 years. As a result, 72.7% (20/165) of our study population had dense breast tissue, with an ACR value of 3 or 4.

Lesion detection rate in the mammography group was significantly lower than in the US and ABVS groups. All eight malignant lesions missed by mammography occurred in higher-density breast tissue, and all were detected by US

and ABVS. Furthermore, three cases missed by US were found by ABVS, which illustrates a key advantage of an automated US system for standardised, reproducible and bilateral whole-breast imaging. This advantage could reduce the probability of missed diagnosis. Relatively high accuracy was achieved in both manual and automated US compared with some previous studies [12]. This might be explained by the fact that all our patients had previous suspicious findings (palpation, US or mammography).

Mammography sensitivity is limited, particularly in young patients [13]. Sensitivity in our group was significantly lower than each method of US. One reason was that most patients had dense breast tissue (ACR 3 and 4), which caused comparatively low mammographic discrimination. Another reason might be that most lesions appeared as masses, and US has been shown to be more sensitive than mammography to masses. However, if mammography was combined with US and ABVS, overall sensitivity increased significantly. In the past, US was used in breast diagnosis mainly in order to distinguish cystic and solid lesions and as a supplementary method to mammography. In our study, both US and ABVS had much better diagnostic sensitivity for solid breast lesions than did mammography, which demonstrates an important role of US in lesion detection [14].

ABVS was the same or better than manual US in terms of accuracy, sensitivity, specificity, PPV and NPV. Differences, however, were not statistically significant ($p>0.05$). ABVS can be more complete than manual US image data for evaluating breast masses because each sectional plane of the saved volume can be visualised. In particular, ABVS could provide a coronal-plane image, which does not have sound attenuation and thus allows better observation of lesion margin. ABVS may also avoid investigator-dependent and nonstandardised documentation. Studies show that 3D US improves breast lesion analysis when compared with conventional US [15]. In our studies, ABVS detection rate, accuracy, sensitivity and specificity were all higher than those of manual US. This result was similar to previous studies: Kotsianos-Hermle et al. [14] showed a sensitivity of 97.5% and a specificity of 88.5% for manual 2D US and of 96.5% and 92.3%, respectively, for manual 3D US of palpable lesions.

US findings used to characterise a solid breast mass include shape, orientation, margin, echogenicity, echotexture, posterior acoustic transmission, boundary echo and presence of calcifications [16]. Some studies previously assessed the value of the criteria in discriminating between benign and malignant masses and concluded that margin characteristics are associated with the highest diagnostic value [15, 17]: 3D US can be used to evaluate these features more completely in focal breast lesion classification. We found most benign lesions (67.7%) had a continuous hyperechoic rim. Spiculated and stellate margins had a high specificity (98.4%) in diagnosing malignant lesions. These were similar to the study of Rotten et al. [15], which described typical findings of breast cancer and fibroadenoma at 3D US on the basis of 186 cases. Benign tumours were often surrounded by a continuous hyperechoic rim, whereas breast cancers had a discontinuous hyperechoic rim on coronal images.

In a study of 100 patients by Nelson et al. [18], 3D US image quality was significantly lower than that of 2D US for a variety of organ systems. We found that the inferior imaging quality in the coronal plane did not affect ABVS diagnostic accuracy and sensitivity. One reason was that ABVS can display transverse, sagittal and coronal planes at the workstation, which could make up for the deficiency of coronal plane. Another limitation of ABVS is that it is still limited when displaying microcalcification. We found that malignant lesions missed by ABVS were clustered microcalcifications. The main limitation of this study is that benign lesions confirmed by pathology should receive a long-term follow-up to confirm stability.

In summary, ABVS is a promising diagnostic adjunct to mammography, and the retraction phenomenon in the coronal plane of 3D US has high diagnostic capability to differentiate between benign and malignant breast lesions. However, ABVS diagnostic accuracy, sensitivity and specificity are almost identical to those of manual US in breast imaging and thus is not preferred over manual US examination.

Conflict of interest None

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