Thieme

SOFIA: A Novel Automated Breast Ultrasound System Used on Patients in the Prone Position: A Pilot Study on Lesion Detection in Comparison to Handheld Grayscale Ultrasound

SOFIA: neuartiges automatisiertes Brustultraschallsystem für Patientinnen in Bauchlage: eine Pilotstudie über die Erkennung von Anomalien im Vergleich mit einem Ultraschall-Handgerät

OPEN ACCESS

Authors
André Farrokh[1], Harika Erdönmez[2], Fritz Schäfer[3], Nicolai Maass[1]

Affiliations
1 Universitätsklinik Schleswig-Holstein, Campus Kiel, Klinik für Gynäkologie und Geburtshilfe, Kiel, Germany
2 Klinikum Bremerhaven-Reinkenheide, Frauenklinik, Bremerhaven, Germany
3 Universitätsklinik Schleswig-Holstein, Campus Kiel, Mammazentrum, Klinik für Gynäkologie und Geburtshilfe und Klinik für Radiologie und Neuroradiologie, Kiel, Germany

Key words
breast, sonography, mammary gland tumor

Schlüsselwörter
Mamma, Mammakarzinom, Ultraschall, Brustdrüsentumor

received 14.2.2018
revised 31.3.2018
accepted 1.4.2018

Bibliography
DOI https://doi.org/10.1055/a-0600-2279
Geburtsh Frauenheilk 2018; 78: 499–505 © Georg Thieme Verlag KG Stuttgart · New York | ISSN 0016-5751

Correspondence
Dr. med. André Farrokh
Universitätsklinik Schleswig-Holstein, Campus Kiel,
Klinik für Gynäkologie und Geburtshilfe
Arnold-Heller-Straße 3, 24105 Kiel, Germany
afarrokh@online.de

ABSTRACT

Introduction Most of the currently available automated breast ultrasound systems require patients to be in the supine position. Previous data, however, show a high recall rate with this method due to artifacts. The novel automated breast ultrasound scanner SOFIA scans the breast with the patient in a prone position, resulting in even compression of breast tissue. We present our initial results with this examination method.

Material and Methods 63 patients were analyzed using a handheld B-mode ultrasound. In cases of BI-RADS 1, 2 or 5, a SOFIA scan was performed. Sensitivity, specificity and accuracy were calculated. Interobserver agreement was evaluated using Cohen's kappa. The duration of the scan was measured for both methods.

Results No BI-RADS 5 lesion was missed with SOFIA. The SOFIA had an additional recall rate of 16.67% compared to B-mode ultrasound. The sensitivity, specificity and accuracy of SOFIA was 100, 83.33 and 88.89%, respectively. Cohen's kappa showed substantial agreement ($\kappa = 0.769$) between examiner 1 (B-mode) and examiner 2 (SOFIA). The mean scan duration for the B-mode system and the SOFIA system was 24.21 minutes and 12.94 minutes, respectively. In four cases, D-cup breasts were not scanned in their entirety.

Conclusion No cancer was missed when SOFIA was used in this preselected study population. The scanning time was approximately half of that required for B-mode ultrasound. The additional unnecessary recall rate was 16.67%. Larger D cup-size breasts were difficult to position and resulted in an incomplete image in four cases.

ZUSAMMENFASSUNG

Einleitung Bei der Mehrzahl der kommerziell erhältlichen automatisierten Brustultraschallsysteme muss die Untersuchung in Rückenlage durchgeführt werden. Allerdings weisen Daten aus früheren Studien auf eine hohe Wiedereinbestellrate mit dieser Methode hin aufgrund von Artefakten. Der neuartige automatisierte Ultraschallscanner SOFIA untersucht die Brust, während die Patientin in Bauchlage auf einem speziellen Untersuchungstisch liegt. Das Brustgewebe wird in dieser Lage gleichmäßig komprimiert. Die ersten Untersuchungsergebnisse mit diesem neuartigen System werden hier vorgestellt.

Material und Methoden Insgesamt wurden 63 Patientinnen mit einem Ultraschall-Handgerät im B-Mode untersucht. Wurde ein Befund als BI-RADS 1, 2 oder 5 eingestuft, wurde anschließend ein Ultraschall mit dem SOFIA-Scanner durchgeführt. Die Sensitivität, Spezifität und Genauigkeit wurden berechnet. Die Übereinstimmung zwischen Beurteilern wurde anhand von Cohens-Kappa-Koeffizienten bestimmt. Die Untersuchungsdauer für beide Methoden wurde gemessen.

Ergebnisse Das SOFIA-System hat keinen BI-RADS-5-Befund übersehen. Verglichen mit dem Ultraschallgerät im B-Mode hatte der SOFIA-Ultraschallscanner eine Wiedereinbestellrate von 16,67 %. Die Sensitivität, Spezifität und Genauigkeit des SOFIA-Scanners betrug jeweils 100, 83,33 und 88,89 %. Der Cohens-Kappa-Koeffizient zeigte weitgehende Übereinstimmung ($\kappa = 0{,}769$) zwischen Beurteiler 1 (B-Mode) und Beurteiler 2 (SOFIA). Die durchschnittliche Untersuchungsdauer für das B-Mode-Ultraschallgerät und das SOFIA-Gerät betrug 24,21 Minuten bzw. 12,94 Minuten. In 4 Fällen wurde eine Brust mit Körbchengröße D nicht vollständig visualisiert.

Schlussfolgerung Beim Einsatz des SOFIA-Systems wurde kein Karzinom in dieser ausgewählten Gruppe von Patientinnen übersehen. Die Scandauer mit dem SOFIA-Ultraschallgerät war ungefähr halb so lang wie mit dem Ultraschallgerät im B-Mode. Die Wiedereinbestellrate für den SOFIA-Scanner betrug 16,67 %. Die Positionierung von größeren Brüsten (Körbchengröße D) stellte sich als schwierig heraus und führte in 4 Fällen zu einem unvollständigen Bild.

Introduction

Breast cancer is the most common cancer among women in all industrialized countries. Screening mammography can detect cancer at an early stage and help to initiate immediate treatment; however, the sensitivity of digital mammography for detecting breast cancer is strongly dependent on breast density and declines to 48 % for patients with the densest breasts [1]. This group of patients requires individual clarification since it is known that a dense breast is an independent risk factor for breast cancer [2 – 4].

B-mode ultrasound is not influenced by breast density, is commonly available, and has the advantage of not exposing the patient to radiation. Furthermore, supplemental breast ultrasound as an adjunct to mammography helps to increase the cancer detection rate by 5.3 per 1000 women [5, 6]. However, performing a handheld ultrasound (HHUS) of both breasts, including history taking and clinical examination, takes approximately 20–30 minutes and the physician must be present continuously. Automated breast ultrasound (ABUS) systems seem to be promising tools for overcoming the time-consuming process of HHUS whilst also possessing the same benefits that B-mode imaging has in the diagnosis of breast lesions in dense breasts. The first ABUS system was introduced almost 50 years ago [7], and several manufacturers have developed devices where patients are examined in the supine position [8 – 10]. The examination box of the ultrasound device, which contains the approximately 10-cm wide ultrasound probe, is positioned on the breast and automatically moves in one direction. The ultrasound probe is attached to the breasts via a flexible membrane on the underside of the examination box and easily adapts to the breast contour. The scanned raw data is subsequently reconstructed in a workstation to a 3D dataset, which allows analysis of the breast in all planes, in a manner similar to tomography.

Although it achieves a fairly high sensitivity, one major problem of the ABUS is the reported high recall rate due to artifacts or incomplete breast imaging, which results in reduced specificity [11]. In HHUS, an artifact can often be easily distinguished from a suspicious lesion by changes in the contact pressure of the ultrasound probe on the skin or by changes in the angle of the probe.

This pilot study used the newly introduced ABUS system, named SOFIA, where patients lie in the prone position during the examination. The idea of using the prone position is not new as the first system named Octoson was introduced more than 40 years ago [12]. In that first setting using the Octoson the breast was positioned in a water tank without any compression and eight ultrasound scanners were used to generate an ultrasound image. However, the diagnostic approach of the newly developed SOFIA system is different. Here, the breast is not positioned in a water tank, but is compressed by the patient's body weight, which forces the breast against the surface of the SOFIA bed. The rationale behind this examination position is that the breast is flattened by contact with the lying surface and the resulting compression of the tissue allows a more homogeneous ultrasound echo frequency pattern than in the supine position. The exact positioning of the patient is explained in detail in the Material and Methods section.

To the best of the authors' knowledge, this is the first study to focus on the use of this new SOFIA device. The aims of this pilot study were to check whether the new ABUS system could recognize all lesions that could be seen in HHUS and to communicate the initial experiences for the examination procedure and the possible limitations of this imaging method.

Materials and Methods

This prospective pilot study was conducted according to the protocol of the latest World Medical Association Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects and was approved by the local ethics committee.

Patient cohort

The study recruited 63 patients with a mean age of 57.95 years (range: 35–81 years) who attended the outpatient service from May 2016 to June 2016. All patients were scheduled for a conventional B-mode ultrasound at the breast center for special diagnostic queries such as palpable lumps, ultrasound imaging in high-risk situations, suspected cancer, or benign lesions. B-mode ultrasound was initially performed as planned, and the image was classified according to the American College of Radiology Breast

Imaging Reporting and Data System (BI-RADS) [13]. The patient was positioned in the supine position for HHUS. All grayscale ultrasound examinations were performed by examiner one (F. S.), who had over 15 years of experience in breast ultrasounds, using the Philips EPIQ 7 ultrasound device equipped with the L12-5 transducer (range: 5–12 MHz) (Philips Medical Systems DMC GmbH, Hamburg, Germany). All B-mode pictures were digitally stored. The patient was asked to participate in the pilot study if the final HHUS assessment revealed an unambiguously benign lesion (BI-RADS 2), a malignant lesion (BI-RADS 5), or no lesion (BI-RADS 1). In this study, the final BI-RADS category assessed by the B-mode ultrasound was used as the gold standard to which the diagnostic accuracy of the new ABUS system was compared.

SOFIA examination procedure

The SOFIA scan was performed after written informed consent was obtained. All SOFIA images were acquired using the Hitachi automated whole breast ultrasound system with a 92 mm high-resolution ultrasound probe and a frequency of 5–10 MHz (Hitachi Medical Systems GmbH, Wiesbaden, Germany). This device consists of three different parts, the first of which is the SOFIA bed (▶ **Fig. 1**) on which the patient lies in the prone position. The bed has a small recess in which the ultrasound probe is located (▶ **Fig. 2**). The probe is sealed by a layer of glass on which the ultrasound gel is applied. The patient is positioned in such a way that the breast comes to rest in the recess. The breast flattens out as it touches the glass with the applied ultrasound gel. The SOFIA bed with the integrated 92 mm ultrasound probe is connected to the ultrasound device Noblus (Hitachi Medical Systems GmbH), which works as a transient raw data storage device. The automated breast scan is started using a touch screen located on the SOFIA bed when the patient is positioned correctly with the nipple in the center of the ultrasound area.

The ultrasound probe moves in a clockwise direction in a circular motion until a full 360° scan of the breast is completed. The reason for the circular scanning technique is the possibility to scan the entire breast with only one scan and thus save time. We would like to emphasize that the aim of this approach is not to enable ductal echography. A scan of one breast takes 35 seconds. The trapezoid linear probe extends the field of view to more than 10 cm, and it can scan breast tissue up to a depth of 6 cm. As with conventional probes, there are additional features, such as HI Definition Tissue Harmonic Imaging and HI Compound Imaging, implemented into the system to improve the SOFIA image quality. After the scan is finished, raw data from the ultrasound device is sent to the SOFIA workstation, which consists of a personal computer with a hard drive and a software solution which enables the examiner to view the 3D reconstructed images in all planes (e.g. sagittal, transversal, coronal, and radial) and make measurements.

The steps from patient positioning and data acquisition to data transfer were carried out by medical assistants and a physician did not need to be present during this procedure.

▶ **Fig. 1** SOFIA bed. The SOFIA bed with a recess at the top end. The ultrasound device, Noblus, functions as an intermediate raw data storage and is positioned on the right side of the bed.

▶ **Fig. 2** Ultrasound scanning area. Magnification of the ultrasound recess in the SOFIA bed in which the breast is positioned in. The nipple should be placed in the center of the recess so that the breast is evenly distributed in the field of view of the ultrasound probe (white arrow) during the scanning procedure.

Image evaluation

All data sent to the workstation were digitally stored and evaluated by examiner two (A. F.) who had 13 years of experience in breast ultrasound. Examiner two had no information on the history of the patient and was only aware that BI-RADS 1, 2, and 5 findings were included in the study while BI-RADS 3 and 4 lesions

were not. Examiner two had software tools that enabled them to scroll through the reconstructed 3D picture of the breast, change the angle or plane of the scan, and perform measurements. The standard procedure in this study was to scan the coronal plane from the skin to the chest wall. When a suspicious region was seen in the coronal plane, the axial and sagittal planes were used to confirm a lesion in at least two planes. Finally, examiner two decided the BI-RADS category for the SOFIA image. The examiner knew that there were no BI-RADS 0, 3, and 4 lesions in this study, therefore they were only allowed to use BI-RADS 1, 2, and 5 for categorization. If the examiner asked for a second-look HHUS due to ambiguous findings or possible suspicious artifacts, this was rated as BI-RADS 0. If a second-look HHUS was requested for a scan without a proven lesion, the SOFIA reading was rated as false positive. Conversely, if a second-look HHUS was requested for an actual malignant lesion, the SOFIA reading was rated as true positive.

Statistical analysis

The descriptive statistics were initially calculated for the acquired data. The sensitivity, specificity, and accuracy with the respective 95% confidence intervals were subsequently analyzed. Finally, the interobserver agreement between the rating of examiner one using HHUS and examiner two using SOFIA was calculated using Cohen's kappa. According to Landis and Koch, κ values of 0.81–1 were regarded as almost perfect agreement, 0.61–0.80 as substantial, 0.41–0.60 as moderate, 0.21–0.40 as fair, 0.00–0.20 as slight, and < 0 as no agreement.

SPSS (V 14.0, SPSS, Inc, Chicago, IL) statistical software was used for all calculation, and $p < 0.05$ was regarded as statistically significant.

Results

The experimental setting using the SOFIA system reached a sensitivity of 100% (95% CI: 83.89–100%), a specificity of 83.33% (95% CI: 68.64–98.03%), and a diagnostic accuracy of 88.89% (▶ **Table 1**).

▶ **Table 1** Sensitivity, specificity, and accuracy of the respective imaging method.

	SOFIA	95% CI
Sensitivity	100%	83.89–100%
Specificity	83,33%	68,64–98.03%
Accuracy	88,89%	78.44–95.41%

CI: confidence interval

Distribution of BI-RADS categories for HHUS and SOFIA

▶ **Table 2** shows the distribution of the BI-RADS rating of a lesion using HHUS and SOFIA. Using HHUS as the gold standard for analyzing breast lesions, there were 22 BI-RADS 1 lesions, 20 BI-RADS 2 lesions, and 21 BI-RADS 5 lesions. For the 41 BI-RADS 2 and 5 lesions, the lesion size was measured with HHUS and a mean lesion size of 17.98 mm (range: 5–48 mm; SD: 10.92) was reported. All 21 tumors rated as BI-RADS 5 by HHUS were detected with SOFIA. In 14 cases, the primary assessment as BI-RADS 5 by HHUS was the same as with SOFIA. In 7 cases, the examination by SOFIA was rated as BI-RADS 0, therefore a second-look ultrasound assessment was induced and none of the lesions were missed. In two of these cases, the recall was explained by shadowing artifacts which did not allow a final assessment. The remaining five cases were suspicious and examiner two was not able to make a final assessment as to the BI-RADS category by the SOFIA images provided. Therefore the examiner requested a second-look ultrasound in these five cases.

Of the 20 BI-RADS 2 lesions, 12 were correctly rated as BI-RADS 2 using SOFIA; however, four lesions were rated as BI-RADS 1 meaning that these four benign lesions were not detected by SOFIA. The remaining four BI-RADS 2 lesions were rated as BI-RADS 0 by SOFIA and resulted in unnecessary second-look ultrasounds. Artifacts were identified in two cases which prevented a final assessment, and incomplete images of the breast were produced in another two cases. Both incomplete images were acquired from a D-cup breast.

SOFIA correctly classified 19 of the 22 breast scans rated as BI-RADS 1; however, three BI-RADS 1 scans in which no lesion was detectable were rated as BI-RADS 0, one because of artifacts and two because of incomplete breast images. Again, these two incomplete images were acquired from D-cup breasts.

▶ **Table 2** Distribution of BI-RADS categorization for the respective imaging method (n). Recall rate for a second-look HHUS (%).

		HHUS			
		BI-RADS 1	BI-RADS 2	BI-RADS 5	Total (n)
SOFIA	BI-RADS 1	19	4	0	23
	BI-RADS 2	0	12	0	12
	BI-RADS 5	0	0	14	14
	BI-RADS 0	3	4	7	14
	Total (n)	22	20	21	63
	Recall rate	13.64%	20.00%	100.00%	

Recall rate

In summary, in addition to the 21 second-look ultrasounds requested by SOFIA for the BI-RADS 5 lesions, an additional seven lesions were rated as false positive and therefore resulted in an unnecessary second-look ultrasound. This equaled 13.64% of second-look ultrasound requests for BI-RADS 1 lesions where no lesion was present and 20.00% of second-look ultrasound requests for BI-RADS 2 lesions. In total, an additional recall rate of 16.67% was noted for SOFIA.

Interobserver agreement

The Cohen's kappa value was calculated to estimate the interobserver agreement. Examiner one performed HHUS and had access to clinical history and clinical examination as additional information. Examiner two had the SOFIA scans and the age of the patients but did not have any additional information. The Cohen's kappa value (κ) = 0.769, indicating substantial agreement between examiner one and two.

Examination procedure

The examination duration was measured for all cases. The mean duration for HHUS was 24.21 minutes (range: 14–32 minutes; SD: 3.96), which included the clinical examination, the whole breast HHUS, and the final assessment of the images. The examination duration for SOFIA included the whole breast ultrasound, image evaluation, and the final assessment. Clinical examination was not part of the SOFIA procedure as the physician did not see the patient but only analyzed the 3D volume data on the workstation. The mean duration of the SOFIA examination was 12.94 minutes (range: 8–19 minutes; SD: 2.16), which amounted to 53.45% of the duration of the HHUS. The SOFIA image acquisition time, beginning with getting the patient ready for positioning and acquiring the scans of both breasts but not including the evaluation of the images, had a mean duration of 3.84 minutes (range: 2–10 minutes; SD: 1.67). For D-cup breasts, it was difficult to position the breast centrally in the scanning area. Four times this resulted in not all the breast tissue being scanned and therefore a final assessment was not possible.

Discussion

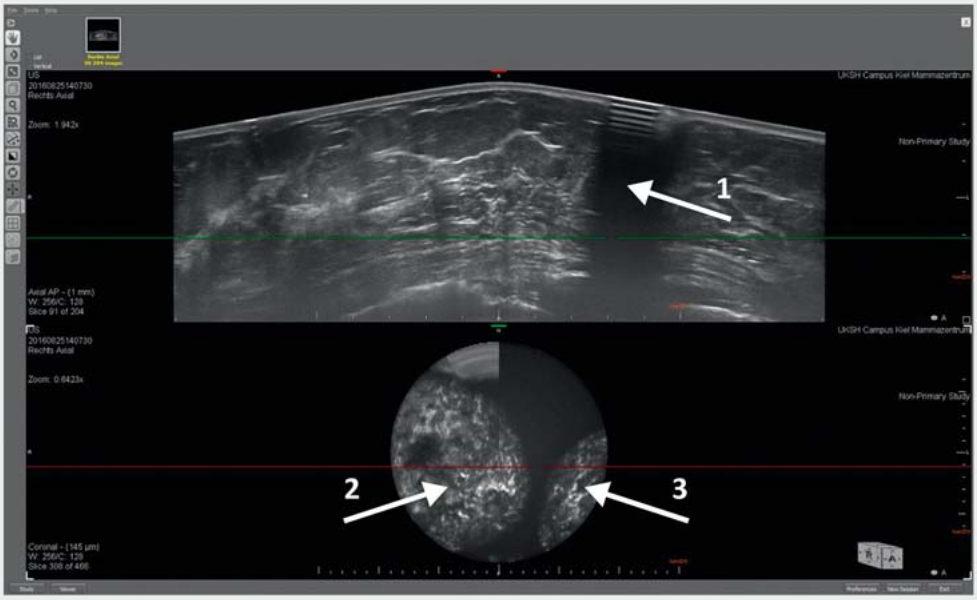
Modern ABUS systems from several manufacturers have emerged on the market in the last 10 years. They have numerous areas of application, such as monitoring the response to chemotherapy or preoperative planning of the resection volume using the coronal plane as the so-called surgical view [14, 15]. However, one main topic is the use of ABUS devices as an adjunct to mammography in very dense breasts. Mammography is known to have a diagnostic gap and decreased sensitivity for very dense breasts and thus cancers may not be recognized [1]. Recently published studies have highlighted the ability of this method to detect additional cancers in very dense breasts. A study evaluating 1668 asymptomatic women with dense breasts found an additional 2.4 cancers per 1000 women when using ABUS in addition to mammography [16]. The study showed that an increase in sensitivity of up to 36.4% in this setting is possible in comparison to mammography alone; however, an increase in the recall rate for a second-look ultrasound due to artifacts or incomplete imaging has to be taken into account, thus resulting in a decrease in specificity [17].

Most ABUS devices on the market are supine-type scanners. The scanner is positioned on the breast with a soft pad assuring good contact with the skin. A large ultrasound probe then moves in one direction to scan the breast. All raw images are transferred to a workstation where the 3D dataset is reconstructed for analysis in all planes. However, this poses a problem for larger breasts as the ultrasound probe has to be repositioned three or four times to get a full scan of the entire breast [18] and this process is time-consuming.

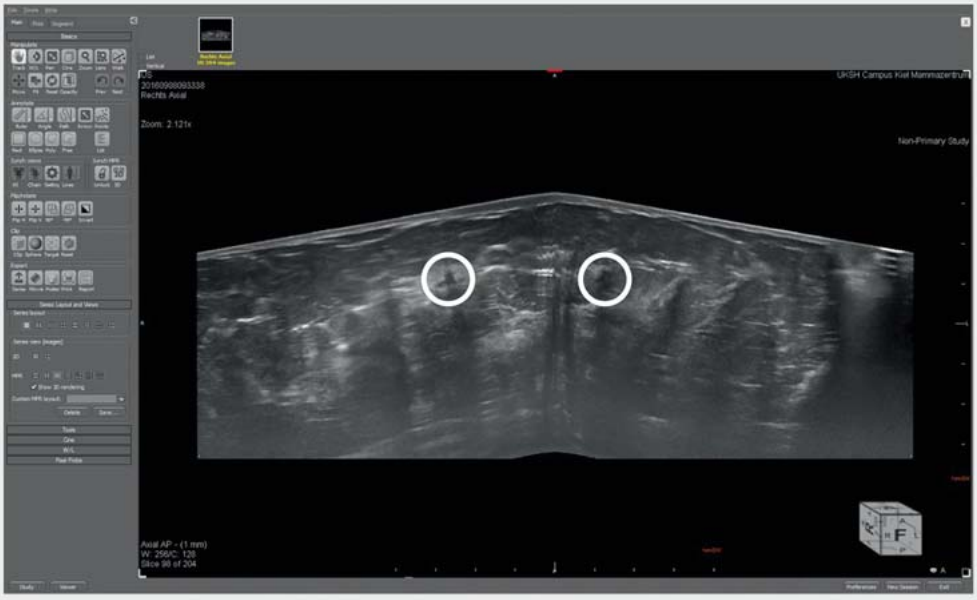
The newly introduced ABUS device, SOFIA, uses a different approach. The patient lies on the SOFIA bed in the prone position and the breast rests in a small recess. The prone position ensures good contact with the glass layer directly above the ultrasound probe due to the compression caused by the patient's body weight. This results in evenly-flattened breast tissue and causes homogenous echogenicity. Furthermore, one entire scan of the breast takes 35 seconds and the patient does not have to adjust their position nor does the ultrasound have to be realigned. This results in a mean examination duration of 3.84 minutes, which is shorter than that of supine ABUS systems [19].

In this experimental setting, in which HHUS was used as the gold standard to which SOFIA was compared, no cancer was overlooked. This resulted in a sensitivity of 100%; however, it should be noted that two of the BI-RADS 5 lesions were recalled for a second-look ultrasound, not because a suspicious lesion was seen on the SOFIA 3D images but because of artifacts that did not allow a final assessment. The overall specificity reached 83.33%. In a similar study design for a preliminary study on a supine ABUS system, the specificity reached 52.8% [11]. The higher specificity in the current study was attributed to the fact that the coupling of the breast tissue to the glass surface in front of the ultrasound probe appears more even and the breast tissue flattens due to the weight of the patient lying in the prone position. Therefore this method generated fewer artifacts, which normally make images harder to interpret. As mentioned earlier, one limitation of this system is the size of the breast. We noticed that D-cup sized breasts were difficult to position correctly in the ultrasound area due to the size of the breast exceeding the scanning area (▶ **Fig. 3**). This problem occurred four times throughout the study and resulted in an incomplete assessment and a request for a second-look HHUS. Furthermore, a limitation that all ABUS devices have in common is their inability to assess unclear structures by changing the amount of applied pressure, changing the angle of the ultrasound probe, or using Doppler or elasticity imaging to differentiate lesions from artifacts. ▶ **Fig. 4** shows a SOFIA scan from a breast with two lesions that was rated BI-RADS 0; however, in a conventional B-mode ultrasound these potential lesions were dissolved immediately when the amount of pressure was increased and the angle of the probe was altered. The images provided (▶ **Figs. 3** and **4**) indicate pitfalls of this new method that have to be addressed. On the other hand, none of the malignant lesions was overlooked.

It was expected that reviewing the data using SOFIA would lead to a total recall of 21 cases, as there were 21 BI-RADS 5 lesions seen with HHUS. In this study, an additional recall rate of



▶ **Fig. 3** Incomplete scan of a D-cup sized breast. A 3D image of a D-cup sized breast. Arrow 1: The shadowing artifact because of the space in between the right and left breast. Arrow 2: The right breast is displayed approximately 75%. Arrow 3: The left breast is displayed accidentally because the positioning of the breast was insufficient.



▶ **Fig. 4** False positive findings with SOFIA. Axial view of the breast with two suspicious areas that lead to the request for a recall for a second-look ultrasound. The image shows two hypoechoic lesions with indistinct margins and posterior shadowing (white circles). In B-mode ultrasound, no lesions were found.

16.67 % was noted for SOFIA. The situation would have been clarified in the assessment; however, the waiting time until clarification would have generated a psychological burden and uncertainty for the patient, which was avoidable.

Limitations

The study population was small and therefore does not represent the overall population. Thus these initial findings should only be understood as a trend within a feasibility study that must be further evaluated in larger prospective studies. Furthermore, the circular scanning technique used by the SOFIA system reminds one of the ductal echography approach. However, we noticed during this study that the complete imaging of a duct is limited due to compression and angulation of the ducts which moves them out of the scanning plane. This led to the evaluation protocol used in this study in which we focused on the coronal plane and then adding the axial or sagittal plane in a second step.

Conclusion

The new SOFIA device that places a patient in the prone position during the examination did not miss any cancer in the preselected study population, and the specificity of this method was higher than preliminary studies using an ABUS system where patients were in the supine position. The examination time was approximately half as long as for HHUS. Furthermore, once the patient was positioned for the scan, no readjustments needed to be made. In addition, it took approximately 35 seconds for one scan to be completed and the whole breast digitalized for further evaluation. However, problems occur with larger breasts with a D cup as these exceed the ultrasound area, make it hard to position the breast centrally, and result in an incomplete image of the breast.

One advantage of the prone position is that it results in good contact with the ultrasound area and the subsequent flattening of the breast creates a homogeneous echo pattern and makes it easier to analyze the images. Based on this feasibility study, it seems reasonable and promising to prepare a larger prospective study that examines this new method outside of a preselected patient population.

Acknowledgements

Some of the data from this study are partial aspects of Harika Erdönmez's doctoral thesis.

Conflict of Interest

The SOFIA device was made available to the study site by Hitachi Medical Systems (Wiesbaden, Germany) free of charge for this feasibility study.

References

[1] Kolb TM, Lichy J, Newhouse JH. Comparison of the performance of screening mammography, physical examination, and breast US and evaluation of factors that influence them: an analysis of 27,825 patient evaluations. Radiology 2002; 225: 165–175

[2] Ursin G, Ma H, Wu AH et al. Mammographic density and breast cancer in three ethnic groups. Cancer Epidemiol Biomarkers Prev 2003; 12: 332–338

[3] Byrne C, Schairer C, Wolfe J et al. Mammographic features and breast cancer risk: effects with time, age, and menopause status. J Natl Cancer Inst 1995; 87: 1622–1629

[4] McCormack VA, dos Santos Silva I. Breast density and parenchymal patterns as markers of breast cancer risk: a meta-analysis. Cancer Epidemiol Biomarkers Prev 2006; 15: 1159–1169

[5] Berg WA, Bandos AI, Mendelson EB et al. Ultrasound as the primary screening test for breast cancer: analysis from ACRIN 6666. J Natl Cancer Inst 2016; 108: djv367. doi:10.1093/jnci/djv367

[6] Berg WA, Blume JD, Cormack JB et al. Combined screening with ultrasound and mammography vs. mammography alone in women at elevated risk of breast cancer. JAMA 2008; 299: 2151–2163

[7] Maturo VG, Zusmer NR, Gilson AJ et al. Ultrasound of the whole breast utilizing a dedicated automated breast scanner. Radiology 1980; 137: 457–463

[8] Mundinger A. 3D Supine Automated Ultrasound (SAUS, ABUS, ABVS) for supplemental screening women with dense breasts. J Breast Health 2016; 12: 52–55

[9] Shin HJ, Kim HH, Cha JH. Current status of automated breast ultrasonography. Ultrasonography 2015; 34: 165–172

[10] Jeh SK, Kim SH, Choi JJ et al. Comparison of automated breast ultrasonography to handheld ultrasonography in detecting and diagnosing breast lesions. Acta Radiol 2016; 57: 162–169

[11] Wojcinski S, Farrokh A, Hille U et al. The Automated Breast Volume Scanner (ABVS): initial experiences in lesion detection compared with conventional handheld B-mode ultrasound: a pilot study of 50 cases. Int J Womens Health 2011; 3: 337–346

[12] Hackeloer BJ, Lauth G, Duda V et al. New aspects in ultrasound mammography. Geburtsh Frauenheilk 1980; 40: 301–312

[13] D'Orsi CJ, Sickles EA, Mendelson EB et al. ACR BI-RADS® Atlas, Breast Imaging Reporting and Data System. Reston, VA: American College of Radiology; 2013

[14] Wang X, Huo L, He Y et al. Early prediction of pathological outcomes to neoadjuvant chemotherapy in breast cancer patients using automated breast ultrasound. Chin J Cancer Res 2016; 28: 478–485

[15] Wang HY, Jiang YX, Zhu QL et al. Differentiation of benign and malignant breast lesions: a comparison between automatically generated breast volume scans and handheld ultrasound examinations. Eur J Radiol 2012; 81: 3190–3200

[16] Wilczek B, Wilczek HE, Rasouliyan L et al. Adding 3D automated breast ultrasound to mammography screening in women with heterogeneously and extremely dense breasts: report from a hospital-based, high-volume, single-center breast cancer screening program. Eur J Radiol 2016; 85: 1554–1563

[17] Brem RF, Tabar L, Duffy SW et al. Assessing improvement in detection of breast cancer with three-dimensional automated breast US in women with dense breast tissue: the SomoInsight Study. Radiology 2015; 274: 663–673

[18] Golatta M, Franz D, Harcos A et al. Interobserver reliability of automated breast volume scanner (ABVS) interpretation and agreement of ABVS findings with hand held breast ultrasound (HHUS), mammography and pathology results. Eur J Radiol 2013; 82: e332–e336

[19] Wojcinski S, Gyapong S, Farrokh A et al. Diagnostic performance and inter-observer concordance in lesion detection with the automated breast volume scanner (ABVS). BMC Med Imaging 2013; 13: 36