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FULL PAPER

Precision imaging—its impact on image quality and diagnostic confidence in breast ultrasound examinations

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Objective: To determine the effect of noise-reducing innovation—precision imaging (PI)—on image quality and diagnostic efficacy in breast ultrasound.

Methods: The study, which assessed four levels of PI from zero to three, consisted of two parts: image quality assessment and diagnostic efficacy evaluation. For the first part, 247 sets of ultrasound images displayed at each PI level were evaluated by 6 experienced breast imaging observers, by rating image quality using visual grading analysis on a 1–4 scale. For the diagnostic efficacy part 51 breast lesions were displayed at each PI level and scored 1–6 to generate a receiver operating characteristic (ROC) curve. These images were evaluated by radiologists and sonographers. Analyses were performed using non-parametric Friedman and Wilcoxon signed rank tests and a multireader multicase methodology.

Results: Statistically, higher scores of image quality were observed with increased levels of PI than with the zero setting ($p < 0.001$). The ROC analysis did not demonstrate any significant change in diagnostic efficacy, with mean scores for all observers being 0.79, 0.80, 0.81 and 0.81 for settings zero, one, two and three, respectively.

Conclusion: This study suggested a perceived improvement in image quality with increasing levels of PI; however, no changes in diagnostic efficacy were noted. The importance of looking at the impact of new imaging technologies in a multifaceted way is emphasized.

Advances in knowledge: To our knowledge, this is the first article investigating the impact of the PI algorithm on ultrasound image quality and breast lesion characterization.

INTRODUCTION

Ultrasound is a highly useful but operator-dependent imaging modality for breast disease diagnosis. The variation in composition of glandular and other tissues, in addition to the subtlety of alterations in echotexture or architectural change which occur owing to pathological processes, can make detection and interpretation of breast lesions difficult. Accurate diagnosis of malignancies requires a process of competent visual search, recognition of potential abnormalities and accurate cognitive assessment.¹

Good image quality is reported to reduce operator dependence and to improve diagnostic confidence.^{2,3} There have been many major improvements in ultrasound image quality since its initial clinical use in the 1970s, as a result of advancements in electronic and computational capabilities, as well as significant developments in transducer design: lateral resolution has been enhanced through the use of a higher centre frequency and an increased number of transducer elements; higher axial resolution has been achieved by increased scanner bandwidth. These improvements have led

to more effective pre- and post-processing of ultrasound signals and images with higher signal-to-noise ratios.⁴

Optimal image quality is highly subjective, but, in general, operators and those who interpret images prefer low noise levels.⁵ There are a number of factors that affect noise, a major one of these being subresolution scatter, which causes coherent interference of backscattered ultrasound signals. This results in a type of granular noise known as speckle, which degrades spatial and contrast resolution and reduces the detection of small, low-contrast targets of critical importance in breast imaging. One study looking at speckle reduction algorithms using a two-dimensional textural homogeneity histogram and directional averaging filters, demonstrated improved diagnostic accuracy, sensitivity and specificity by approximately 15%, 6% and 9%, respectively.⁶ However, other studies focusing on tissue harmonics and spatial compounding methods to reduce speckle have demonstrated that, even though there is a quantifiable improvement in image quality, there was no measurable difference in diagnostic performance.^{7,8} The

current picture regarding the efficacy of speckle reduction technology remains unclear. The present work investigates a speckle reduction algorithm, precision imaging (PI). According to the manufacturer (Toshiba Medical Systems Corporation, Tochigi-ken, Japan), this algorithm can differentiate between random noise inputs and signals critical to patient information. It modifies the data to construct images that are less noisy and which demonstrate sharpened contours or boundaries at important interfaces.⁹ The technology can be applied in conjunction with other ultrasound techniques, such as spatial and frequency image compounding, tissue harmonic imaging (THI) and colour Doppler imaging, without affecting frame rate or increasing image delay. A study focused on focal liver lesions concluded that PI software produced images with better lesion conspicuity, sharper margins and overall improved image quality.¹⁰ However, the efficacy of the PI algorithm in breast imaging is unknown.

The aim of this work was to explore the impact of PI on breast image quality and lesion characterization using expert observers. To this end, we used two analytic methods: visual grading analysis (VGA) to investigate image quality appearances of normal breast tissue and benign lesions and receiver operating characteristic (ROC) analysis to determine observers' ability to discriminate between malignant and benign conditions.

METHODS AND MATERIALS

Patient and case selection

Patients aged from 20 to 84 years examined at the Sydney Breast Clinic (Sydney, NSW) between October 2010 and June 2011 were included in the study. The Human Research Ethics Committee of the University of Sydney approved (protocol number 14466) the study and patients provided consent.

Cases were selected based on their clinical grading using the Royal Australian and New Zealand College of Radiologists five-point scoring system:¹¹ one, normal; two, definitely benign; three, indeterminate/equivocal; four, suspicious of malignancy;

five, definitely malignant. According to the clinic's regular practice, the nature of all lesions that were given a score of three, four or five was determined by fine needle aspiration and/or core biopsy pathology. Lesions with a score of two, definitively benign, were a mix of cysts and solid lesions. Some benign lesions with appearances of solid lesions were biopsied if they were the patient's presenting symptom and the rest were shown to be stable over time.

Two sets of cases were chosen, one for each of the two parts of the study (Study 1: VGA; Study 2: ROC). For Study 1, 247 cases (scored 1 or 2) were chosen, of which 92 cases showed normal breast parenchyma, 140 cases contained benign fluid-filled lesions and a further 15 demonstrated benign solid lesions. For Study 2, 51 cases were selected: 4 and 16 were lesions scored 3 and 4, respectively, in the clinic and later proven to be malignant; 20, 10 and 1 were lesions originally scored 2, 3 and 4, respectively, and later proven to be benign. Details on the lesion type and size are given in Table 1.

Image acquisition and processing

The commercial ultrasound scanner Toshiba AplioMX, Model SSA-780A (Toshiba Medical Systems Corporation), with compact linear transducers 15-7 MHz (PLT-1204BT) and 12-5 MHz (PLT-805AT) were used for image acquisition, with the choice of transducer depending on the size and density of the breast. The breast was first scanned using the standard departmental protocol, which included optimizing each of the following: time gain compensation, centre frequency of transmitting ultrasound and depth of the image. THI was applied to all images.

Once the standard imaging was completed, a single projection image that was considered to best represent the lesion or normal breast parenchyma was captured four times, once as a baseline with no additional algorithm applied (L0), then with each of the three PI levels—L1, L2 and L3, with the higher number signifying greater speckle reduction. All other pre- or post-processing

Table 1. Types of lesion chosen for Study 2—receiver operating characteristic analysis

Lesions	Types	Number of cases	Size range (mm)
Malignant	Invasive ductal carcinoma	17	7–28
	Invasive lobular carcinoma	1	9
	Ductal carcinoma <i>in situ</i>	2	12
Benign	Fat necrosis	3	7–19
	Fibroadenoma	8	9–17
	Fibrocystic changes	7	7–21
	Hyperplasia without atypia	2	7 and 9
	Intraduct papilloma	2	5 and 7
	Fibrosis	1	7
	Phyllodes	1	24
	Sclerosing lymphocytic lobulitis	1	10
	Stable lesions for ≥ 2 years without fine needle aspiration	6	5–13

settings remained the same, and the collected images were cropped so that the patients' identity and all technical factors, including the PI level, were removed.

Observer studies

Study 1—visual grading analysis

For the VGA, the four images (L0, L1, L2 and L3) for each case were displayed simultaneously as shown in Figures 1 and 2 using ViewDex (viewer for digital evaluation of X-ray images) software (Sahlgrenska University Hospital, Göteborg, Sweden). The allocation of images with different PI levels to specific quadrants was randomized in each case. The images were reviewed by one radiologist and five sonographers, all with at least 5 years' experience in breast imaging. All observers were asked to rank each of the four images within each case from one to four in the order of image quality, with a score of one indicating the highest quality.

Study 2—receiver operating characteristic analysis

For the ROC analysis, 4 sets of images were created, each set consisted of all 51 lesions with the same level of applied PI, and images were randomly arranged within each set using Ziltron viewing software (Ziltron, Limerick, Ireland). Six radiologists and six sonographers read all images in the order in which image sets were presented being different for each observer. Each lesion was scored using a one to six scale: one, definitely benign; two, probably benign; three, possibly benign; four, possibly

malignant; five, probably malignant; and six, definitely malignant. The observers were blinded to all clinical and imaging history.

For both VGA and ROC analyses, there was no time limit on scoring; all images were displayed at full native resolution; and zooming was available.

Statistical analysis

Non-parametric Friedman test was used for the overall VGAs with the Wilcoxon tests being employed for paired comparisons between L0 and for each of the other three PI levels.

For the ROC analysis, Scores 1–3 were defined as negative and Scores 4–6 were defined as positive. ROC analysis used the Dorfman, Berbaum, Metz multireader multicase approach and again paired comparisons between L0 and each of the other three pairings were performed. A Mann–Whitney *U* test was also used to determine whether there were statistically significant differences for ROC area under curve (AUC) values between the observer groups (radiologists and sonographers) and since no statistically significant intergroup differences were found, observers were (for part of the analysis) then combined as a single group. A Wilcoxon signed rank test was also used to determine whether there were statistically significant differences in sensitivity or specificity between any of the PI pairings, where

Figure 1. An example of a typical image showing a fluid-filled lesion as presented to the observers; in this case, the order was: (a) L1, (b) L0, (c) L3 and (d) L2.

Figure 2. An example of a typical image showing a normal breast parenchyma as presented to the observers; in this case, the order was: (a) L0, (b) L3, (c) L1 and (d) L2.

sensitivity was the ratio of true positive (TP) over the combined value of TP and false negative and specificity was the ratio of true negative (TN) over the combined value of TN and false positive.

RESULTS

Study 1—visual grading analysis

Observer VGA scores at specific PI values for all images grouped together, along with Friedman test ranking, are shown in Table 2. Statistically significant differences can be observed for all participants between PI levels. The paired testing

demonstrated significant findings for a number of observers for each pairing with most significant outcomes being noted for the L0 vs L3 comparison (Table 3). All significant findings at this specific comparison demonstrated lower scores (increased quality) at the higher than the lower level of PI.

When images were broken into normal and benign groups, significant findings were demonstrated for both groups of images for Observers 2–6 (including the radiologist observer). Observer 1 demonstrated a difference for only benign images (Table 4). The

Table 2. Assessment using visual grading analysis of image quality for all images grouped together

Observers	L0	L1	L2	L3	χ^2	<i>p</i> -value
Observer 1	2.52	2.68	2.34	2.46	8.443	0.04 ^a
Observer 2	2.8	2.36	2.6	2.23	28.56	<0.001 ^a
Observer 3	2.64	2.7	2.38	2.28	18.543	<0.001 ^a
Observer 4	2.54	2.87	2.34	2.24	34.789	<0.001 ^a
Observer 5	2.73	2.72	2.42	2.12	37.366	<0.001 ^a
Observer 6	2.81	2.65	2.52	2.02	53.049	<0.001 ^a
Median	2.69	2.69	2.40	2.24		

Note that the lower score implies a higher level of image quality.

The numbers represent the observer visual grading analysis scores at specific precision imaging levels.

^aSignificant findings.

Table 3. Wilcoxon signed rank test results for all images grouped together

Observers	L1–L0		L2–L0		L3–L0	
	Z	p-value	Z	p-value	Z	p-value
Observer 1	−1.70	0.09	−1.30	0.19	−0.82	0.41
Observer 2	−4.43	<0.001 ^a	−1.46	0.15	−4.63	<0.001 ^a
Observer 3	−0.68	0.50	−1.89	0.06	−3.28	0.01 ^a
Observer 4	−3.44	0.001 ^a	−1.59	0.11	−2.87	0.004 ^a
Observer 5	−0.30	0.77	−2.40	0.02 ^a	−5.75	<0.001 ^a
Observer 6	−0.94	0.35	−2.54	0.01 ^a	−6.15	<0.001 ^a

In paired analysis the lower scores indicate increased image quality.

^aSignificant findings.

paired testing again showed a number of significant differences with most of these occurring at the L0 vs L3 pairing (Table 5). Again lower scores (higher quality) were generally shown at the higher rather than at the lower level of PI.

Study 2—receiver operating characteristic, sensitivity and specificity analyses

ROC AUC values are given in Table 6, and sensitivity and specificity values are shown in Table 7. No statistically significant differences were found for any of the observer groups (radiologists, sonographers or all grouped together).

DISCUSSION

Previous studies have shown that speckle reduction improves the visual perception of tissue differentiation, delineation of tissue boundaries and depiction of internal architecture.^{9,12–16} Whilst

these image quality benefits are known, there has been less emphasis in the literature on the impact of these technologies on diagnostic efficacy. This study addresses this deficiency by determining the impact of a novel speckle reduction method on both image quality and diagnostic efficacy in one of the most challenging radiological environments—breast imaging.

Given the importance of identification of subtle pathological tissue changes, maximization of image quality is vital to facilitate perception of abnormalities. This is particularly critical in a clinical breast-screening environment, where only about 5 in 1000 images will contain pathology and a quick decision is needed.¹⁷ Our evaluation of image quality used VGA of paired comparisons of anatomical and benign structures. It demonstrated increasing observer preference for images with higher PI levels (greater speckle reduction) with statistically significant differences.

Table 4. Visual grading analysis assessment of image quality for normal and benign images considered separately

Observers	Tissue type	L0	L1	L2	L3	χ^2	p-value
Observer 1	Normal	2.59	2.63	2.40	2.38	4.47	0.21
	Lesion	2.54	2.74	2.28	2.44	10.27	0.02 ^a
Observer 2	Normal	2.77	2.55	2.53	2.15	18.81	<0.001 ^a
	Lesion	2.81	2.32	2.57	2.31	15.93	0.001 ^a
Observer 3	Normal	2.63	2.79	2.39	2.19	17.91	<0.001 ^a
	Lesion	2.70	2.62	2.36	2.33	9.51	0.02 ^a
Observer 4	Normal	2.54	2.88	2.30	2.28	21.43	<0.001 ^a
	Lesion	2.63	2.81	2.37	2.19	21.25	<0.001 ^a
Observer 5	Normal	2.71	2.78	2.45	2.05	30.19	<0.001 ^a
	Lesion	2.76	2.66	2.35	2.22	17.91	<0.001 ^a
Observer 6	Normal	2.84	2.65	2.47	2.04	32.99	<0.001 ^a
	Lesion	2.76	2.67	2.5	2.07	26.62	<0.001 ^a
Median	Normal	2.67	2.72	2.43	2.17		
	Lesion	2.73	2.67	2.37	2.27		

Note that the lower score implies a higher level of image quality.

The numbers represent the observer visual grading analysis scores at specific precision imaging values.

^aSignificant findings.

Table 5. Wilcoxon signed rank test results for all images for normal and benign images considered separately

Observers	Tissue type	L1–L0		L2–L0		L3–L0	
		Z	p-value	Z	p-value	Z	p-value
Observer 1	Normal	−0.38	0.71	−1.13	0.26	−1.68	0.09
	Lesion	−1.79	0.07	−1.58	0.11	−0.94	0.35
Observer 2	Normal	−1.47	0.14	−1.54	0.12	−4.05	<0.001 ^a
	Lesion	−4.01	<0.000 ^a	−1.36	0.18	−3.16	0.002 ^a
Observer 3	Normal	−1.53	0.13	−1.47	10.14	−3.05	0.002 ^a
	Lesion	−0.43	0.67	−1.98	0.05 ^a	−2.57	0.01 ^a
Observer 4	Normal	−2.95	0.003 ^a	−1.47	0.14	−1.88	0.06
	Lesion	−1.60	0.11	−1.65	0.10	−3.24	0.001 ^a
Observer 5	Normal	−0.91	0.36	−1.70	0.09	−4.67	<0.001 ^a
	Lesion	−0.46	0.64	−2.39	0.02 ^a	−3.97	<0.001 ^a
Observer 6	Normal	−0.80	0.42	−2.60	0.01 ^a	−4.79	<0.001 ^a
	Lesion	−0.29	0.77	−1.71	0.09	−4.39	<0.001 ^a

In paired analysis the lower scores indicate increased image quality.

^aSignificant findings.

As noted previously, all images were initially obtained using THI, a speckle reduction technique, which decreases artefacts from shallow structures as well as overall image clutter in the near field.¹⁸ However, when this is used in combination with PI, additional image quality improvement can be demonstrated. The benefits of combining different types of technologies have been shown previously in similar contexts, when compounding techniques and computer enhancement (XRES®; Philips

Ultrasound, Inc., Bothell, WA) together produced superior images to compounding alone.¹⁹

Although our VGA presented promising findings, no improvements in diagnostic efficacy were detected using ROC assessment. Whilst speckle reduction can increase the conspicuity of low-contrast lesions^{12,20} and improve perception of subtle image details,^{5,21} the absence of an effect of PI on performance in the

Table 6. Receiver operating characteristic values for each observer at different precision imaging levels. Mean values are given for radiologists (R) (Observers 1–6), sonographers (S) (Observers 7–12) and all observers. Standard deviation (SD) values are shown in parentheses

Observer	L0	L1	L2	L3
1	0.78	0.77	0.83	0.76
2	0.79	0.82	0.75	0.79
3	0.79	0.81	0.83	0.80
4	0.76	0.79	0.79	0.78
5	0.79	0.77	0.86	0.88
6	0.81	0.79	0.85	0.77
R mean (SD)	0.79 (0.06)	0.79 (0.06)	0.82 (0.05)	0.80 (0.05)
7	0.79	0.78	0.80	0.84
8	0.82	0.80	0.88	0.78
9	0.82	0.85	0.84	0.85
10	0.87	0.83	0.81	0.85
11	0.71	0.77	0.82	0.74
12	0.80	0.82	0.67	0.82
S mean (SD)	0.80 (0.06)	0.81 (0.05)	0.80 (0.06)	0.82 (0.06)
Overall mean (SD)	0.79 (0.05)	0.80 (0.05)	0.81 (0.05)	0.81 (0.05)

No significant difference in ROC values across different precision imaging levels.

Table 7. Sensitivity and specificity values for each observer at different precision imaging levels. Mean values are given for radiologists (R) (Observers 1–6), sonographers (S) (Observers 7–12) and all observers. Standard deviation (SD) values are shown in parentheses

Observer	Sensitivity				Specificity			
	L0	L1	L2	L3	L0	L1	L2	L3
1	0.75	0.85	0.9	0.75	0.81	0.74	0.68	0.52
2	0.75	0.9	0.8	0.8	0.81	0.68	0.74	0.71
3	0.8	0.85	0.8	0.7	0.55	0.65	0.71	0.81
4	0.75	0.85	0.85	0.9	0.68	0.61	0.65	0.58
5	0.85	0.75	0.95	0.95	0.61	0.77	0.71	0.77
6	0.75	0.7	0.7	0.7	0.81	0.77	0.84	0.77
R mean (SD)	0.78 (0.04)	0.82 (0.08)	0.83 (0.09)	0.80 (0.10)	0.71 (0.12)	0.70 (0.07)	0.72 (0.07)	0.69 (0.12)
7	0.6	0.55	0.7	0.7	0.87	0.84	0.87	0.84
8	0.8	0.8	0.9	0.75	0.71	0.71	0.68	0.68
9	0.9	0.9	0.9	0.9	0.61	0.52	0.48	0.52
10	0.65	0.65	0.7	0.75	0.87	0.9	0.84	0.84
11	0.55	0.75	0.75	0.7	0.84	0.77	0.87	0.9
12	0.85	0.9	0.7	0.8	0.74	0.71	0.65	0.61
S mean (SD)	0.73 (0.14)	0.76 (0.14)	0.78 (0.10)	0.77 (0.08)	0.77 (0.10)	0.74 (0.13)	0.73 (0.16)	0.73 (0.15)
Overall mean (SD)	0.75 (0.10)	0.79 (0.11)	0.80 (0.09)	0.78 (0.09)	0.74 (0.11)	0.72 (0.10)	0.73 (0.11)	0.71 (0.13)

present study is in line with the findings of Cha et al.⁸ In their studies using the alternate speckle reduction techniques of THI or spatial compounding, they did not show any significant improvement in the characterization of breast lesions. On the other hand, Su et al.⁶ did find increases in diagnostic accuracy when breast images were reprocessed by a speckle reduction algorithm based on a two-dimensional textural homogeneity histogram and directional averaging filters. A limitation of the present study may be the number of ultrasound images presented for evaluation. Su et al used up to six images for each lesion, unlike the work presented here, where a single image was chosen to best represent the lesion and its features.

There are seemingly three possible explanations for an improvement in image quality not impacting on diagnosis. Firstly, lesions with indeterminate features were selected for ROC analysis. Some indeterminate features, such as irregular shape or microlobulation, will remain indeterminate whatever speckle-reducing technology is employed, and diagnostic opinion will not change regardless of differing image quality. Secondly, multiple speckle reduction techniques were used synchronously.

THI was used to enhance the image prior to the application of PI, therefore the image without PI had very little clutter, and this could have reduced the potential impact of PI on diagnostic efficacy. Thirdly and possibly most importantly, all observers were experienced breast radiologists and sonographers. With expertise it has been shown that image abnormality perception follows the “top down theory”, which means that there is parallel processing of the entire retinal image with acquired knowledge about normal and abnormal appearances.¹ Therefore a “good” quality image probably serves the same purpose as an “even better” quality image amongst experts. A further study examining the confidence of professionals with lower levels of expertise may show a greater impact on diagnostic efficacy.

CONCLUSION

A significant increase in the perception of improved image quality was achieved with increasing levels of PI, a novel speckle reduction technology. However, this improvement did not translate into increased diagnostic efficacy amongst expert observers in this study. The importance of assessing new technologies using a variety of analytic approaches has been shown.

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