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FULL PAPER

Interpretation of digital breast tomosynthesis: preliminary study on comparison with picture archiving and communication system (PACS) and dedicated workstation

^{1,2}YOUNG SEON KIM, MD, ¹JUNG MIN CHANG, MD, PhD, ³ANN YI, MD, PhD, ¹SUNG UI SHIN, MD, ^{1,4}MYUNG EUN LEE, PhD, ⁵WON HWA KIM, MD, PhD, ¹NARIYA CHO, MD, PhD and ¹WOO KYUNG MOON, MD, PhD

¹Department of Radiology, Seoul National University College of Medicine, Seoul National University Hospital, Seoul, Republic of Korea

²Department of Radiology, College of Medicine, Yeungnam University, Daegu, Republic of Korea

³Department of Radiology, Gangnam Healthcare Center, Seoul National University Hospital, Seoul, Republic of Korea

⁴Advanced Institutes of Convergence Technology, Seoul National University, Seoul, Republic of Korea

⁵Department of Radiology, Kyungpook National University Medical Center, Daegu, Republic of Korea

Address correspondence to: Prof. Jung Min Chang

E-mail: jmchangjm@gmail.com

Objective: To compare the diagnostic accuracy and efficiency in the interpretation of digital breast tomosynthesis (DBT) images using a picture archiving and communication system (PACS) and a dedicated workstation.

Methods: 97 DBT images obtained for screening or diagnostic purposes were stored in both a workstation and a PACS and evaluated in combination with digital mammography by three independent radiologists retrospectively. Breast Imaging-Reporting and Data System final assessments and likelihood of malignancy (%) were assigned and the interpretation time when using the workstation and PACS was recorded. Receiver operating characteristic curve analysis, sensitivities and specificities were compared with histopathological examination and follow-up data as a reference standard.

Results: Area under the receiver operating characteristic curve values for cancer detection (0.839 vs 0.815,

$p = 0.6375$) and sensitivity (81.8% vs 75.8%, $p = 0.2188$) showed no statistically significant differences between the workstation and PACS. However, specificity was significantly higher when analysing on the workstation than when using PACS (83.7% vs 76.9%, $p = 0.009$). When evaluating DBT images using PACS, only one case was deemed necessary to be reanalysed using the workstation. The mean time to interpret DBT images on PACS (1.68 min/case) was significantly longer than that to interpret on the workstation (1.35 min/case) ($p < 0.0001$).

Conclusion: Interpretation of DBT images using PACS showed comparable diagnostic performance to a dedicated workstation, even though it required a longer reading time.

Advances in knowledge: Interpretation of DBT images using PACS is an alternative to evaluate the images when a dedicated workstation is not available.

INTRODUCTION

Using mammography (MG) for screening of breast cancer in asymptomatic females has been shown to reduce breast cancer-related mortality^{1–6} in conjunction with advances in treatment. The overall sensitivity of MG including film screen and digital mammography (DM) for the detection of breast cancer is 77–95%⁷ and it varies with breast density. The most likely cause of recall is a dense breast that can obscure a lesion by superimposition of fibroglandular tissue. Tissue superimposition has a masking effect that limits detection of non-calcified breast cancers. Thus, the sensitivity of film screen MG is lower (30–48%) in females

with dense breasts.^{8–12} Digital breast tomosynthesis (DBT) for breast imaging was invented in the 1990s to overcome tissue superimposition.^{13,14} In DBT, partial three-dimensional reconstruction of multiple sequential views of the breast can potentially overcome tissue superimposition.^{13–19} DBT can provide potential advantages for detection of mass, architectural distortion and asymmetry in comparison with conventional two-dimensional mammographic images.¹⁸ Many studies have demonstrated the benefits of DBT in terms of increased cancer detection and reduced recall rates.^{20–24} However, in spite of its advantage, DBT has several limitations, such as longer

interpretation time than full-field DM¹⁶ and the need for large storage capacity. Furthermore, it needs its own dedicated workstation to analyse the DBT images. In most clinical practices, the work-up for breast lesions starts with MG, and all exams are read in batches even with the addition of DBT studies using their own workstation. Sometimes, breast ultrasonography or MR images can be interpreted together with DBT images, and intermodality correlations are often needed to integrate all the information in patients with known breast carcinoma. Currently, the picture archiving and communication system (PACS) is able to store DBT data using the digital imaging and communication in medicine (DICOM) standard format, thus making it possible for radiologists to evaluate DBT images on PACS using tools integrated with PACS. By using PACS for DBT interpretation, it would be easier to store the image data and access the case using computers located anywhere. If using a PACS for reading the DBT does not affect the accuracy and efficiency of diagnosis, accessibility of DBT and convenience of radiologists will be improved.

Therefore, the purpose of this study was to compare the diagnostic accuracy and efficiency in interpretation of DBT images using PACS and a dedicated workstation.

METHODS AND MATERIALS

Study population

This retrospective study was approved by our institutional review board and the requirement for informed consent was waived. Between June and November 2013, females who underwent DBT in our institution for both screening and diagnostic purposes were consecutively selected. Among them, those who had DBT images stored and technically available for reading on both a dedicated workstation and PACS were included. Among 109 females, 12 with a history of surgery and postoperative surgical scar seen on MG were excluded. A total of 97 females who underwent DBT for diagnostic ($n = 50$) and screening purposes ($n = 47$) were included (mean age 48.2 years, range 22–76). The cancer detection rate was rather high in the study population, as our cases were largely composed of diagnostic cases because of the characteristics of our institution—a tertiary care centre with a large referral base. All malignant and benign tumours were confirmed through core-needle biopsy (14-gauge automated gun or 11-gauge vacuum-assisted) or surgical excision. All patients who had no evidence of breast malignancy on follow-up MG after 2 years were considered negative or benign findings.

Imaging acquisition

All DBT and DM were performed by one dedicated technologist using a commercially available device (Selenia Dimensions System; Hologic, Bedford, MA). The device used a custom-designed high-power tungsten anode X-ray tube and rhodium, silver, aluminium X-ray filters. Different filters in DBT and DM imaging modes produce optimal X-ray spectra (20–49 kVp) based on the thickness/composition of the breast using automatic exposure control. DBT and DM images were obtained in each breast with craniocaudal and mediolateral oblique projections. The image receptor was a 70 μm pixel pitch selenium direct capture detector. The X-ray tube rotated over a 15° arc while

the breast was compressed, taking a series of ultra-low-dose mammograms. The projections were reconstructed to create a three-dimensional image set of the breast with 1 mm slices thorough the breast.^{24–27}

All DBT images were stored using DICOM secondary capture object format in a dedicated workstation and DICOM digital breast tomosynthesis object (BTO) format in PACS.

Image preparation and display

The DBT images were evaluated using a PACS viewer (INFINITT PACS; Infinitt Healthcare, Seoul, South Korea) and dedicated workstation (SecurView workstations; Hologic) with two 21-inch black and white monitors (ME 551i2; Totoku, Tokyo, Japan). The monitors had a matrix of 2048 $\times$ 2560 with an 11-bit depth. The maximum brightness was 750 cd m^{-2} . Monitor luminance was calibrated as recommended by the suppliers. Two identical monitors were located side by side on the same table in a standard reading room without ambient light. Images were displayed using a 1 $\times$ 1 layout in each monitor and viewed in a stack or cine mode. Reading of DBT using PACS and a dedicated workstation was performed in the same room.

Observer performance study

Three radiologists (13, 13, and 5 years of experience in MG, respectively) independently read 97 DBT images using a dedicated workstation in one session and using PACS during the next session. They interpreted these cases as baseline cases without comparisons, and any other images including prior examination or any additional special views were not available to the readers for this review session. Readers had an average of 2.7 years (range 1–5 years) of experience of DBT using the dedicated workstation, and they were trained using instructional files of 100 cases of tomosynthesis. Two separate reading sessions were performed with at least a 4-week interval to minimize any learning bias. Each reading session contained half of the images displayed on a dedicated workstation and half of the images displayed on PACS, randomized and presented in alternating order. All images were anonymized, and the readers were blinded to the patient's histological diagnosis as well as any clinical or laboratory information. Each reader was requested to review the DBT images and record the number and location of all lesions on the standardized recording paper with a graphical interface. They also rated the likelihood of malignancy (%) and recorded the Breast Imaging-Reporting and Data System (BI-RADS) categories for each case. For cases in which more than one lesion was suspected, the abnormality with the highest suspicion was recorded. Cases categorized as BI-RADS 1, 2 or 3 were regarded normal or benign, and cases categorized as BI-RADS 4 or 5 were regarded abnormal or malignant.

The interpretation time for each case using the dedicated workstation or PACS were recorded separately. We also evaluated the image quality of DBT displayed on PACS using BTO format compared with the dedicated workstation. If the image quality on PACS was not good enough to make a diagnosis, we assessed that case as “non-diagnostic”. If the image quality on PACS was inferior compared with the dedicated workstation, but interpretable,

we assessed that case as “inferior, but diagnostic”. If there was no difference in image quality between PACS and the dedicated workstation, we assessed that case as “equal”.

Reference standard

Two radiologists (J.M.C and Y.S.K) matched the breast lesions between each imaging modality and pathology via consensus. They have 13 (J.M.C) and 5 years (Y.S.K) of experience in breast imaging. They used the standardized recording papers with the graphical interface for radiological review and pathological reports of surgical and biopsied specimens for pathological review. For all patients with breast cancer, surgical excisions were performed for their cancer by axillary nodal dissection or sentinel lymph node biopsy. One pathologist (25 years of experience in breast pathology) reviewed the surgical and biopsied specimens. Finally, the breast lesions which were pathologically diagnosed as malignant were regarded positive. The breast lesions which were pathologically diagnosed as benign were regarded negative. The breast lesions for which biopsy was not performed and that showed no evidence of malignancy after 2 years of follow-up (clinically and radiologically) were also regarded negative.

Statistical analysis

Statistical analyses were performed on data obtained from the matched image sets ($n = 97$). A receiver operating characteristic curve analysis was performed to evaluate and compare readers' performances in terms of lesion detection between the interpretation sessions.

In addition, diagnostic sensitivities and specificities of each workstation and each reader for the detection of lesions were calculated and compared with histopathological examination and follow-up data as a reference standard. The threshold for a true-positive was BI-RADS category 4 thus, category 4 or higher was a true-positive rating. These values were compared pairwise using the McNemar test. Two-tailed p -values less than 0.05 were considered statistically significant. Statistical analyses were performed using SPSS v. 19.0 for Windows (IBM Corp., Armonk, NY; formerly SPSS Inc., Chicago, IL) and MedCalc v.12.7 (MedCalc Software, Mariakerke, Belgium).

The interobserver variability was assessed by comparing the difference in the detection of cancer among the three radiologists using PACS and the dedicated workstation Kappa statistic. Landis criteria was used to interpret Kappa statistic: poor ($\kappa < 0.20$), fair ($\kappa = 0.21-0.40$), moderate ($\kappa = 0.41-0.60$), good ($\kappa = 0.61-0.80$) and very good ($\kappa = 0.81-1.0$) agreement.²⁸

RESULTS

The clinicopathological characteristics of the 97 patients are shown in Table 1. Of the 97 patients, 22 had malignant tumours, 25 had benign tumours and 50 were negative. Table 2 summarizes areas under the receiver operating characteristic curves (A_z) and sensitivities and specificities using PACS and the workstation for each of the three readers and for all readers. Overall, higher A_z values were noted when using the dedicated workstation (0.839) than PACS (0.815), although no statistically significant difference was noted between the dedicated workstation and PACS

Table 1. Clinicopathological characteristics of the 97 patients in our study

Clinicopathological characteristics	No. (%)
Mean age (years)	48.2
Presentation	
Asymptomatic	67 (69.1)
Palpable mass	26 (26.8)
Nipple discharge	4 (4.1)
Breast density	
a, b	21 (21.6)
c, d	76 (78.4)
Pathology	
Negative	50 (51.5)
Benign	25 (25.8)
Malignancy	22 (22.7)
DCIS	4 (18.2)
IDC (with or without DCIS)	18 (81.8)

DCIS, ductal carcinoma *in situ*; IDC, infiltrating ductal carcinoma.

($p = 0.6375$). Overall, sensitivity was higher with the dedicated workstation (81.8%) than PACS (75.8%), but it was not significantly different ($p = 0.2188$) either. Among the 22 malignancies, four cases were more frequently interpreted as true-positive on the workstation than PACS by at least one of the three readers. By contrast, only one case was more frequently interpreted as true-positive on PACS than the workstation by at least one of the three readers. Specificity was significantly higher when analysing on the workstation than when using PACS for one of the three radiologists (reader 3, $p = 0.041$) and on average ($p = 0.009$). Among the 75 benign or negative cases, 21 cases were interpreted more frequently as true-negative on the workstation than PACS (Figure 1) and nine cases were interpreted more frequently as true-negative on PACS than the workstation by at least one of the three readers.

Table 3 summarizes interpretation time of DBT on the workstation and PACS for each of the three readers and for all readers. The mean time to interpret DBT images on PACS (1.68 min/case) was significantly longer than on the workstation (1.35 min/case) ($p < 0.0001$).

Regarding image quality, most of the DBT images displayed on PACS were assessed as equal to (83.2%) or inferior to those displayed on the workstation but diagnostic (16.5%) by the three readers. One reader (reader 3) assessed that only one case was deemed necessary to be reanalysed using the workstation. Using PACS, the case was interpreted as a regionally distributed, punctate calcification and the final assessment was BI-RADS category 3 by reader 3 (Figure 2a). However, using the workstation, the case was interpreted as a fine pleomorphic microcalcification and the final assessment was BI-RADS category 4A by the same reader (Figure 2b). The other two readers interpreted the case as an amorphous or fine pleomorphic microcalcification

Table 2. Performances of readers in detecting cancer with DBT using the dedicated workstation and PACS

Reader	Sensitivity ^a rate (%)		Specificity ^a rate (%)		Accuracy (%)		AUC			
	PACS	Workstation	PACS	Workstation	PACS	Workstation	PACS	p-Value	Workstation	p-Value
Reader 1	72.7 (16/22)	81.8 (18/22)	81.3 (61/75)	84.0 (63/75)	79.4 (77/97)	83.5 (81/97)	0.833	0.000	0.835	0.000
Reader 2	77.3 (17/22)	81.8 (18/22)	74.7 (56/75)	84.0 (63/75)	75.3 (73/97)	83.5 (81/97)	0.828	0.000	0.865	0.000
Reader 3	77.3 (17/22)	81.8 (18/22)	69.3 (52/75)	82.7 (62/75)	71.1 (69/97)	82.5 (80/97)	0.791	0.000	0.814	0.000
Overall	75.8	81.8	76.9	83.7	76.6	83.2	0.815	0.000	0.839	0.000

AUC, area under the receiver operating characteristic curve; BI-RADS, Breast Imaging-Reporting and Data System; DBT, digital breast tomosynthesis; PACS, picture archiving and communication system.

^aSensitivity and specificity were calculated and compared with histopathological examination and follow-up data as a reference standard. The threshold for a true-positive was BI-RADS category 4.

Figure 1. Left mediolateral oblique view of digital breast tomosynthesis in a 45-year-old female with invasive ductal carcinoma showing subtle asymmetry (arrows) in the left upper area of extremely dense breast composition. One of the readers (reader 1) interpreted this as negative on the picture archiving and communication system (a) but positive on the workstation (b).

and the final assessment was BI-RADS category 4B or 4C irrespective of the display method (PACS or workstation). The standard reference for this case was diffuse, punctate calcifications and the final assessment was BI-RADS category 3, with no evidence of breast malignancy after 2 years of imaging follow-up. According to reader 3 the image quality for this case displayed on PACS was non-diagnostic, requiring DBT review on the workstation. However, the reader's interpretation was correct using PACS, but was incorrect using the workstation. As a result, we hypothesized that even though the image quality of DBT displayed on PACS is subjectively worse than that displayed on the workstation, it does not affect the diagnostic performance. Table 4 summarizes evaluation of image quality of DBT displayed on PACS compared with that displayed on the dedicated workstation.

Interobserver variabilities are summarized in Table 5. Using PACS, the agreements between readers 1 and 2 ($\kappa = 0.571$, p -value = 0.000), readers 1 and 3 ($\kappa = 0.516$, p -value = 0.000), readers 2 and 3 ($\kappa = 0.561$, p -value = 0.000) were moderate, while the agreement using workstation is good: readers 1 and 2

Table 3. Interpretation time for DBT

Reader	Interpretation time with PACS (min)		Interpretation time with workstation (min)	
	Total	Mean time for a case (SD)	Total	Mean time for a case (SD)
Reader 1	144	1.48 (± 0.33)	124	1.28 (± 0.34)
Reader 2	158.2	1.63 (± 0.62)	134	1.38 (± 0.25)
Reader 3	187.3	1.93 (± 0.62)	135	1.39 (± 0.30)
Overall	163.2	1.68 (± 0.56)	131	1.35 (± 0.30)

DBT, digital breast tomosynthesis; PACS, picture archiving and communication system; SD, standard deviation.

($\kappa = 0.726$, p -value = 0.000); readers 1 and 3 ($\kappa = 0.671$, p -value = 0.000); readers 2 and 3 ($\kappa = 0.787$, p -value = 0.000) (Table 5).

DISCUSSION

In the present study, we assumed that interpretation of DBT images using a PACS system instead of a dedicated workstation would yield similar diagnostic performance to that obtained using a dedicated workstation. Overall, diagnostic performances and sensitivity were equivalent; however, the specificity was lower with the PACS system.

To take full advantage of DBT images, a proprietary upgraded image display and review station are often required using which one vendor's images can be viewed on another platform without difficulty. Handling the increased volume of images with appropriate speed and refresh rates and performing specialized post-processing such as synthetic two-dimensional views and slab views are

also important. Using recently developed technology, the reconstructed section images in a standard DICOM format are pushed to a PACS²⁹ and viewed in a stack or cine mode, similar to any other volumetric or stacked image series, whereas several of the original PACS vendors have had more difficulty making these rapid changes because of the need to accommodate legacy customers with backward compatibility. The current PACS is practical, a combination acceptable to many practicing radiologists. Images are displayed for a reasonable length of time, and manipulation and annotation of the image can be performed in an acceptable number of steps. The functionality of PACS is doubtless robust enough for the average user.

In this observational study, we compared the performances of a dedicated workstation and PACS for reading DBT images. Normal and abnormal cases were selected from a screening and diagnostic population, and three readers, who were blinded to patient data, read DBT images twice with a 4-week interval using a dedicated workstation and PACS. Overall, A_z values and sensitivities were slightly higher for the dedicated workstation, but no statistical significance was observed. Our results suggest that PACS can be used to interpret DBT images in clinical practice in most clinical cases instead of a dedicated workstation. However, the specificity was significantly higher when analysing on the dedicated workstation than on PACS. This might be due to the fact that the evaluation of shape or margin of mass was more accurate on the workstation than on PACS. So, the final assessment to characterize the lesion may be more accurate with the workstation than PACS. Since only one case was deemed necessary to be reanalysed using the workstation by one radiologist when evaluating DBT images using PACS, and

Figure 2. Digital breast tomosynthesis images of a 44-year-old female with microcalcifications in her left breast. This case was deemed necessary to be reanalysed using the workstation by one of the readers (reader 3). Microcalcifications were more clearly visible on the workstation (b) than on PACS (a).

Table 4. Evaluation of image quality of DBT displayed on PACS (compared with the dedicated workstation)

Reader	Image quality on PACS		
	Non-diagnostic	Inferior, but diagnostic	Equal
Reader 1	0	0	97 (100%)
Reader 2	0	7 (7.2%)	90 (92.8%)
Reader 3	1 (1.0%)	41 (42.3%)	55 (56.7%)
Overall	0.33 (0.34%)	16 (16.5%)	80.7 (83.2%)

DBT, digital breast tomosynthesis; PACS, picture archiving and communication system.

Table 5. Interobserver variability in detecting cancer with DBT using PACS and a dedicated workstation

	PACS	Workstation
Reader 1 vs reader 2		
Kappa	0.571	0.726
p-Value	0.000	0.000
Reader 1 vs reader 3		
Kappa	0.516	0.671
p-Value	0.000	0.000
Reader 2 vs reader 3		
Kappa	0.561	0.787
p-Value	0.000	0.000

DBT, digital breast tomosynthesis; PACS, picture archiving and communication system.

the sensitivity for detection of cancer using PACS was comparable to that of the workstation, we suggest interpretation of DBT images using PACS first, and the use of a dedicated workstation later for better characterization.

The reading time to interpret DBT images using PACS (mean 1.68 min/case) was significantly longer than that using a dedicated workstation (mean time 1.35 min/case). According to a previous study, using workstations dedicated to a single imaging modality can make radiologists waste up to 28 min per day.³⁰ Moreover, the diversity of tools and options available among workstations can make radiologists waste more time, up to 18 min per day.³⁰ For this reason, a longer time to interpret images could be expected when using the dedicated workstation.

However, when comparing only reading time in our study, we found that the time to upload and operate DBT images in stack mode with PACS took more time and that the results were opposite to previous studies. More advanced technology can solve the problem of overall longer reading time.

Our study had several limitations. First, this is a retrospective, single-institution study with only a small number of patients. Second, as we included patients from both the screening and diagnostic population, we could not provide distinct data on diagnostic performances or interpretation time for the specific population. Further larger studies catering to a screening or diagnostic population are warranted. Third, we only evaluated a single type of DBT and PACS machines, which means that the findings cannot be generalized to all other vendors of DBT and PACS machines. Finally, a 4-week interval for reader study might not be enough to eliminate learning and recall bias, because of repeated reading sessions on a limited number of cases.

CONCLUSION

In conclusion, our results show that interpretation of DBT images using PACS has a comparable diagnostic performance to a dedicated workstation, even though it requires a longer reading time. Interpretation of DBT images using PACS is a feasible option to evaluate the images when a dedicated workstation is not available. However, it would be favourable to use the workstation to interpret DBT images in batches to save time and increase specificity.

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