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How long does it take to read a mammogram? Investigating the reading time of digital breast tomosynthesis and digital mammography

George J. W. Partridge [a], Iain Darker [a], Jonathan J. James [b], Keshthra Satchithananda [c], Nisha Sharma [d], Alexandra Valencia [e], William Teh [f], Humaira Khan [g], Elizabeth Muscat [h], Michael J. Michell [c], Yan Chen [a,*]

[a] University of Nottingham, School of Medicine, Translational Medical Sciences, Clinical Sciences Building, City Hospital Campus, Hucknall Road, Nottingham, NG5 1PB, United Kingdom
[b] Nottingham University Hospitals NHS Trust, Nottingham Breast Institute, City Hospital Campus, Hucknall Road, Nottingham NG5 1PB, United Kingdom
[c] Department of Breast Radiology and National Breast Screening Training Centre, King's College Hospital, Denmark Hill, London SE5 9RS, United Kingdom
[d] Leeds Breast Screening Unit, Leeds Teaching Hospital, York Road, Leeds, LS14 6UH, United Kingdom
[e] Avon Breast Screening, Bristol Breast Care Centre, Bristol, BS10 5NB, United Kingdom
[f] North London Breast Screening Service, Edgware Community Hospital, London, HA8 9BA, United Kingdom
[g] City, Sandwell and Walsall Breast Screening Service, Birmingham City Hospital, B18 7QH, United Kingdom
[h] South West London Breast Screening Service, St George's Hospital, London, SW17 0QT, United Kingdom

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ABSTRACT

Purpose: To analyse digital breast tomosynthesis (DBT) reading times in the screening setting, compared to 2D full-field digital mammography (FFDM), and investigate the impact of reader experience and professional group on interpretation times.

Method: Reading time data were recorded in the PROSPECTS Trial, a prospective randomised trial comparing DBT plus FFDM or synthetic 2D mammography (S2D) to FFDM alone, in the National Health Service (NHS) breast screening programme, from January 2019-February 2023. Time to read DBT+FFDM or DBT+S2D and FFDM alone was calculated per case and reading times were compared between modalities using dependent T-tests. Reading times were compared between readers from different professional groups (radiologists and radiographer readers) and experience levels using independent T-tests. The learning curve effect of using DBT in screening on reading time was investigated using a Kruskal-Wallis test.

Results: Forty-eight readers interpreted 1,242 FFDM batches (34,210 FFDM cases) and 973 DBT batches (13,983 DBT cases). DBT reading time was doubled compared to FFDM (2.09 ± 0.64 min vs. 0.98 ± 0.30 min; $p < 0.001$), and DBT+S2D reading was longer than DBT + FFDM (2.24 ± 0.62 min vs. 2.04 ± 0.46 min; $p = 0.006$). No difference was identified in reading time between radiologists and radiographers (2.06 ± 0.71 min vs. 2.14 ± 0.46 min, respectively; $p = 0.71$). Readers with five or more years of experience reading DBT were quicker than those with less experience (1.86 ± 0.56 min vs. 2.37 ± 0.65 min; $p = 0.008$), and DBT reading time decreased after less than 9 months accrued screening experience ($p = 0.01$).

Conclusions: DBT reading times were double those of FFDM in the screening setting, but there was a short learning curve effect with readers showing significant improvements in reading times within the first nine months of DBT experience.

ClinicalTrials.gov Identifier: NCT03733106.

Abbreviations: DBT, Digital Breast Tomosynthesis; FFDM, Full-Field Digital Mammography; S2D, Synthetic 2D Mammography; UK, United Kingdom; NHS, National Health Service; IQR, Interquartile range; SD, Standard Deviation.

* Corresponding author at: University of Nottingham, School of Medicine, Translational Medical Sciences, Clinical Sciences Building, City Hospital Campus, Hucknall Road, Nottingham, NG5 1PB, United Kingdom.

E-mail address: mszyc1@exmail.nottingham.ac.uk (Y. Chen).

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1. Introduction

Using digital breast tomosynthesis (DBT) has been shown to improve breast cancer detection and reduce false positive recalls, compared to using 2D full-field digital mammography (FFDM) alone in screening settings [1–3]. DBT can improve sensitivity and specificity by resolving overlapping layers of breast tissue that could obscure breast cancers and avoiding summation artefacts resulting in false positive interpretations, especially in women with dense breast tissue [4,5].

DBT is commonly employed as a further assessment tool for women recalled in breast screening programmes, yet, for many countries the decision to implement DBT as a screening tool is still under debate. Although DBT can improve diagnostic accuracy, the pseudo-3D DBT images contain much more visual information, taking a longer time to interpret and demanding greater cognitive resources from the reader, potentially leading to greater fatigue, compared to FFDM [6–12]. Many countries are already experiencing a shortage of mammography readers together with an increasing workload, and implementing DBT as the standard screening modality in these circumstances could exacerbate an already challenging situation. Hence, it is critical to understand the role and impact of employing DBT in routine screening.

In the UK, a national, prospective randomised trial (PROSPECTS Trial) is underway, comparing the performance of screening with DBT to the current standard of care, FFDM, in the National Health Service (NHS) breast screening programme [13]. As part of the PROSPECTS Trial, readers recorded the duration to read batches of screening examinations, both DBT and FFDM. The primary aim was to compare the time taken to read DBT screening examinations (always read alongside a 2D mammographic image) and FFDM alone screening examinations. When interpreting DBT screening examinations, an additional aim was to assess the effect on reading time when the DBT images were read alongside either a directly acquired FFDM or a synthetic 2D mammogram generated from the DBT data set (S2D). In the UK, mammograms are double read either by board-certified radiologists, radiographer readers (technologists with Master's-level training in image interpretation) or breast clinicians (physicians who are not radiologists but who work in breast diagnosis) and so the effect of reader professional group and reader experience on reading times was assessed. We also investigated the effect that reader experience in the interpretation of DBT had on reading times. Understanding reading times is crucial when considering logistics of DBT implementation in national screening programmes.

2. Materials and methods

The reading time of screening batches was routinely collected as part of the PROSPECTS Trial, a prospective randomised trial comparing the performance of screening with DBT to FFDM, in the National Health Service (NHS) breast screening programme [13]. The PROSPECTS Trial (ClinicalTrials.gov Identifier: NCT03733106) has London–Dulwich Research Ethics Committee approval and participating patients provided written informed consent. The trial began recruiting from January 2019 and is ongoing. Reading time data collected for this study was for the period January 2019 until February 2023.

2.1. Trial randomisation process and readers

Readers were from six NHS screening centres, participating in the PROSPECTS Trial. Trial screening clinics/sessions were randomised in advance to either control (FFDM) or intervention (FFDM+DBT). Women who attended an appointment at a screening session that was randomised as a control session received standard FFDM only. Women who attended a screening appointment in a session that was randomised as a DBT session were offered DBT screening consisting of both DBT and a FFDM. Some women attending a DBT screening clinic did not consent to DBT and so underwent FFDM only. Consequently, a DBT screening clinic batch consisted of women who consented for DBT screening and women who did not consent and underwent standard FFDM only.

All readers in the trial were NHS Breast Screening Programme (NHSBSP) readers who are required to interpret a minimum of 5000 mammograms per year [14]. Readers in the NHSBSP are from one of three professional groups; radiologists, radiographer readers (technologists) with Master's level training in mammographic image interpretation and breast clinicians (physicians who work in breast screening who are not radiologists). Further information about readers in the NHSBSP, including details of their qualifications and training can be found elsewhere [15,16]. All screening examinations were independently read by two readers according to NHSBSP standard practice [14]. All readers had received NHSBSP approved specialist training in DBT interpretation, consisting of a 1-day course including lectures on DBT interpretation, physics and technology, as well as an 80 case DBT reading exercise with an experience reader. For all readers, the total number of years of experience in mammographic interpretation was recorded as was the number of years of experience in DBT interpretation.

When interpreting DBT screening examinations, the DBT images were always read in conjunction with a 2D mammogram, either a directly acquired 2D FFDM (DBT+FFDM) or a synthetic 2D image generated from the DBT dataset (DBT+S2D). In the PROSPECTS Trial, the first reader interpreted DBT alongside the synthetic 2D mammogram (DBT+S2D) and the second reader interpreted DBT alongside the directly acquired 2D digital mammogram (DBT+FFDM). All readers had access to previous screening examinations if available. All prior screening imaging was FFDM.

Readers input their opinion directly into the National Breast Screening System (NBSS) as either 'normal' or 'abnormal'. NBSS also acts as the Radiology Information System (RIS) and drives the Picture Archiving and Communication System (PACS) and so when a reader records their opinion the next screening case on the worklist is displayed. Readers manually recorded the time when they started reading a batch, and the time they finished, so that the total screening batch reading time could be calculated (more information below).

2.2. Data processing and reading times

The data were split into two groups – breast screening centres 1–5 and breast screening centre 6 (Fig. 1). At breast screening centres 1–5 DBT screening clinic batches consisted of women that consented to participate, who underwent the DBT reading protocol, and the women who did not consent and underwent the standard of care, FFDM, only as previously described. Therefore, readers at centres 1–5, when reading DBT screening clinic batches, read a mix of DBT screening examinations and FFDM only cases. At screening centre 6, non-consenting patients were separated from consenting patients in the reading batches, so readers at screening centre 6 only read DBT examinations when reading DBT screening batches.

Trial readers recorded the time when they started reading a batch and the time when they finished so the total batch reading duration could be calculated. Additionally, readers were able to make comments about the reading session, including the duration of any reading breaks taken. If a break took place, then the break duration was subtracted from the total batch reading time before calculating per case durations. The total number of women, the number of consenting and non-consenting women and the date were also recorded for each reading session. To analyse the DBT and FFDM reading time, the average reading time per case was calculated per batch by dividing the total reading duration by the number of cases read (Equation (1). This method was possible for FFDM batches at all screening centres (1–6), and for DBT batches at screening centre 6 only.

To calculate DBT reading time at screening centres 1–5 the following method was used. First, the mean average FFDM case duration was calculated per reader, based on their reading of FFDM only batches.

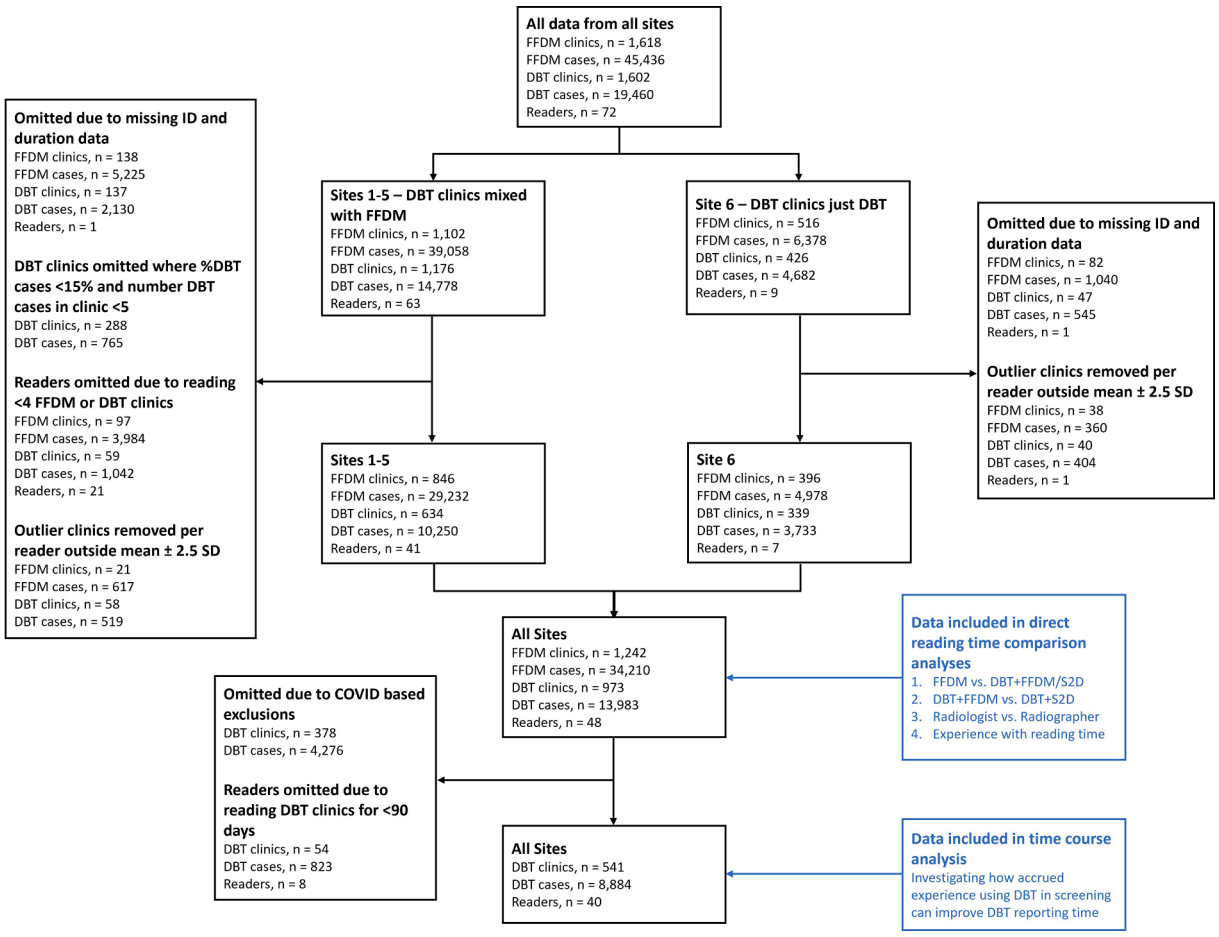

Fig. 1. Exclusions flow chart. Data from sites 1–5 and site 6 were separated due to differences in data collection at these sites, which led to different exclusion criteria for both site groups. After initial exclusions, data from the two sites groups were collated. Another round of exclusions was enforced for the time course analysis investigating how DBT reading time changes with accrued experience using DBT as a screening tool.

Using this information and knowing the total number of FFDM cases in the batch, DBT reading time could be calculated as shown in Eq. (2).

2.3. Exclusions

Exclusions are shown in Fig. 1. Batches were excluded due to missing batch reading duration or reader ID data. For screening centres 1–5, the DBT screening clinic batches contained a mixture of DBT screening examinations and FFDM only screening examinations. Therefore, screening batches containing < 15 % DBT cases were excluded as the average DBT reading durations calculated from these batches would be unreliable (more details can be found in Fig. 1). For all screening centres, readers were excluded if they had read less than four FFDM or DBT batches since this could introduce error into the paired analyses. In an attempt to remove erroneous reading time data resulting from readers not accurately recording reading breaks, batches with average per case durations classified as outliers were removed (data points outside the mean ± 2.5 standard deviations, per reader).

Further exclusions were applied specifically for the time course analysis, which aimed to investigate how DBT reading time changed with accrued experience using DBT as a screening tool. Since the early phase of the PROSPECTS Trial was interrupted by the COVID pandemic, readers were excluded if their first nine months of screening DBT reading experience fell within the period where the PROSPECTS Trial screening was ceased.

$$\textit{Average per case duration, per batch} = \frac{\textit{Batch duration}}{\textit{Number of cases}} \tag{1}$$

$$\textit{Estimated average DBT case duration, per batch} = \frac{\textit{Batch duration} - \left(\textit{Reader's average FFDM case duration} \times \textit{Number of FFDM cases in batch}\right)}{\textit{Number of DBT cases in batch}} \tag{2}$$

2.4. Statistical analysis

Dependent T-tests were used to compare reading time between FFDM vs. DBT (with either FFDM/S2D), and DBT+S2D vs. DBT+FFDM, where readers were matched in both groups. Independent T-tests were used to compare radiologist and radiographer readers, as well as experience levels, where reader cohorts were not matched.

For the time course analysis, DBT clinics were grouped into three, non-overlapping bins of size 90-days. A Kruskal-Wallis test was performed with post-hoc Dunn's tests with Bonferroni corrections to identify significant differences between the three time groupings.

The α-level for statistical significance was set at 0.05. Statistical calculations were performed using Python 3.8.3 (Python Software Foundation) by GP.

3. Results

Forty-eight readers from six NHS breast screening centres were eligible to take part in the study and independently read 1,242 FFDM batches reading a total 34,210 FFDM screening cases and 973 DBT screening clinic batches reading a total of 13,983 DBT examinations (Fig. 1).

3.1. Reader demographics

Radiologists made up 67 % of readers (32 of 48), radiographer readers 29 % (14 of 48) and breast clinicians 4 % (2 of 48). Readers had a median of 10 years (IQR = 12 years) experience in breast cancer screening and a median of 5 years (IQR = 3 years) of experience in DBT interpretation (information on reading experience was not available for three of the screeners).

3.2. Reading time with different modalities

The mean DBT reading time (DBT+S2D and DBT+FFDM) per case was double that of the mean FFDM reading time per case (2.09 ± 0.64 min compared to 0.98 ± 0.30 min, respectively; $p < 0.001$). When DBT was read with a synthetic mammogram, interpretation time was increased by an average of 12 s which was significantly longer than DBT read with directly acquired FFDM (2.24 ± 0.62 min for DBT + S2D compared to 2.04 ± 0.46 min for DBT + FFDM, $p = 0.006$) (Fig. 2).

3.3. Radiologist and radiographer reading times

The reading time for FFDM and DBT was compared between radiologists and radiographer readers. Two readers were excluded from this analysis since they were neither a radiologist nor radiographer. There was no difference in reading times for radiologists and radiographer readers interpreting either FFDM or DBT. Reading times for radiographers and radiologists interpreting FFDM cases was 1.06 ± 0.27 min and 0.91 ± 0.27 min respectively ($p = 0.09$), and for DBT cases 2.14 ± 0.46 min and 2.06 ± 0.71 min respectively ($p = 0.71$) [Fig. 3].

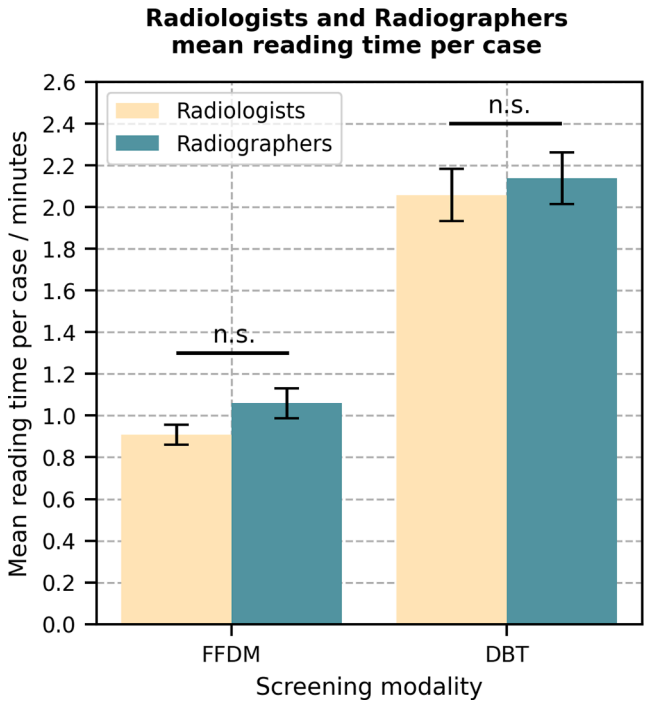

Fig. 3. Bar chart demonstrating the difference in reading time comparing radiologists and radiographers across both screening modalities. Error bars represent the standard error of the mean (SEM), n.s. denotes $p > 0.05$.

3.4. Reader experience

Two measures of experience were available for each reader: (1) the number of years of experience interpreting mammography, and (2) the number of years of experience interpreting DBT. Experience data was unavailable for three readers, and so were excluded from this sub-analysis. There was a trend for readers with more than 10 years of mammography experience (n = 22) to interpret DBT cases quicker than readers with 10 or less years of experience (n = 23), but this did not reach statistical significance (1.91 ± 0.54 min vs. 2.27 ± 0.70 min,

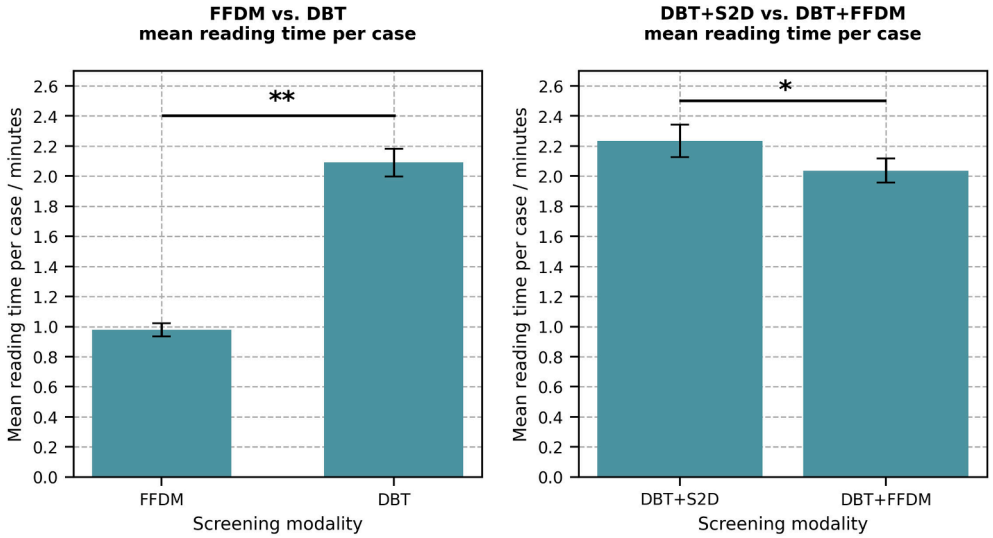

Fig. 2. Bar charts demonstrating the difference in reading time comparing the different modalities. Error bars represent the standard error of the mean (SEM), * denotes $p < 0.05$, ** denotes $p < 0.001$.

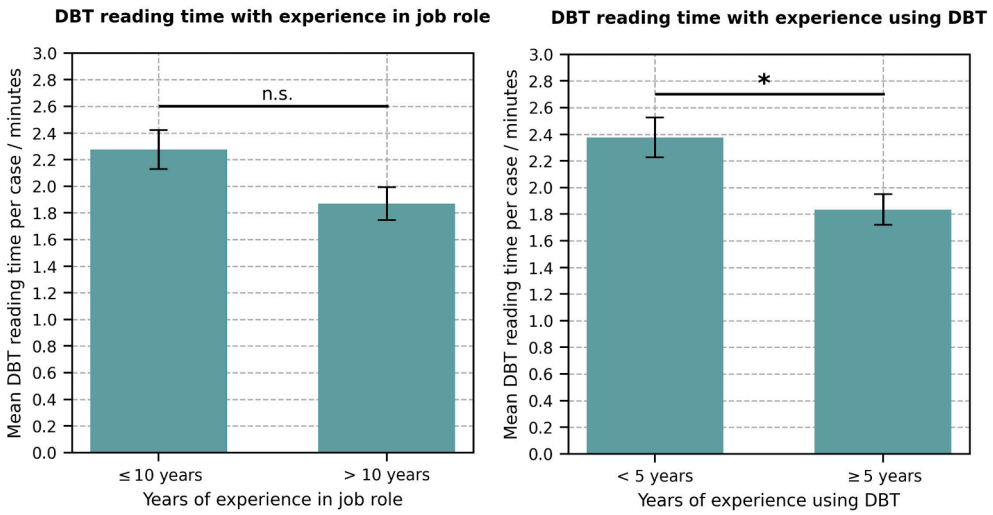

Fig. 4. Bar charts demonstrating the difference in average per case DBT reading time for readers with different experience in job role and using DBT. Error bars represent the standard error of the mean (SEM), * denotes $p < 0.05$.

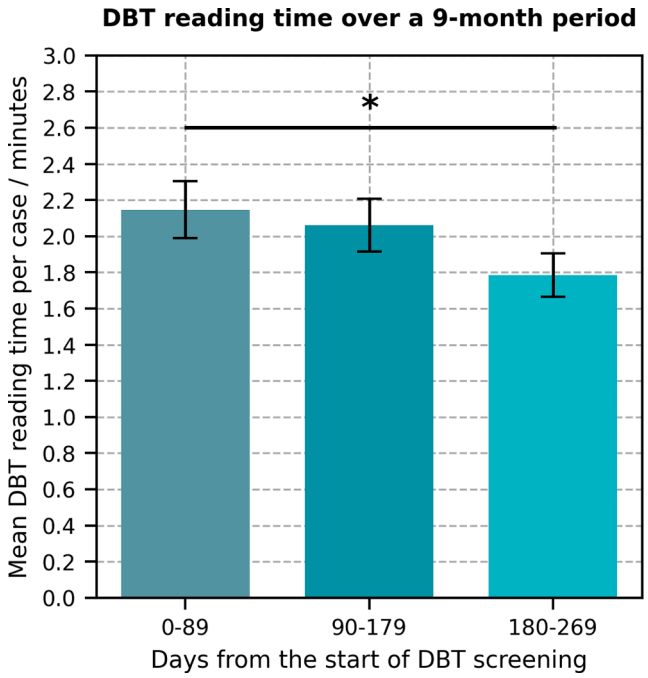

Fig. 5. Bar chart demonstrating the difference in average per case DBT reading time over a 9-month period of screening with DBT. Error bars represent the standard error of the mean (SEM), * denotes $p < 0.05$, n.s. denotes $p > 0.05$.

respectively; $p = 0.06$). Years of experience in the interpretation of DBT had an effect on reading times. Readers with five or more years of experience reading DBT ($n = 24$) were on average 31 s quicker per case compared to those with less than five years of experience ($n = 21$) (1.86 ± 0.56 min vs. 2.37 ± 0.65 min respectively; $p = 0.008$) [Fig. 4].

3.5. Time course analysis

DBT reading times were compared at three-month (90-day) intervals over a nine-month period to investigate if there was any measurable improvement in DBT reading time as readers accrued experience using DBT in the screening setting [Fig. 5]. DBT reading times decreased over the 9-month interval with DBT interpretation times falling from a high of 2.15 ± 0.99 min per case for the first three months (0–89 days) to 1.78 ± 0.66 min per case for the last 3-month period (180–269 days), $p = 0.02$.

4. Discussion

Digital breast tomosynthesis (DBT) can improve the sensitivity and specificity of breast screening, but interpretation is potentially more labour intensive than standard 2D mammography (FFDM). We sought to investigate DBT reading time in the screening setting to determine the impact of DBT implementation in breast screening programmes. We found that DBT required double the reading time compared to FFDM (2.09 ± 0.64 min vs. 0.98 ± 0.30 min, respectively; $p < 0.001$), and that DBT + S2D reading took longer than DBT+FFDM (2.24 ± 0.62 min vs. 2.04 ± 0.46 min, respectively; $p = 0.006$). There was no difference in reading time between radiologists and radiographers (2.06 ± 0.71 min vs. 2.14 ± 0.46 min, respectively; $p = 0.71$). Finally, readers with five or more years of experience reading DBT were quicker at reading DBT than those with less than five years' experience (1.86 ± 0.56 min vs. 2.37 ± 0.65 min; $p = 0.008$), and DBT reading time improved with accrued experience using DBT in screening ($p = 0.01$).

Previous studies have assessed DBT and FFDM reading times in the screening setting [6–10]. In the recent TOSYMA trial in Germany, Heindel and Weigel et al. observed a median interpretation time of DBT + S2D of 109.0 s (71.4–172.8) compared to 54.0 s (33.0–91.2) for FFDM [6]. In the Norwegian To-Be trial, Hofvind et al. reported a mean reading time of 66 s for DBT+S2D compared to 39 s for FFDM [7]. Skanne et al. in the Oslo DBT screening trial measured a mean interpretation time of 91 s for DBT + FFDM compared to 45 s for FFDM alone [8]. In North America, Dang et al reported a mean interpretation of 2.8 min (range 1.5–4.2) for DBT+FFDM compared to 1.9 min (range 1.1–3.0) for FFDM [9]. Absolute interpretation times do differ between studies, reflecting variations in screening practice in different countries, hanging protocols and how interpretation times are measured, but all these studies are in line with our own findings that DBT reading times were double those of FFDM.

In high volume screening programmes where double reading is the standard of care, a doubling of reading times could seriously affect screening workflow, leading to unmanageable workloads, reader fatigue and burnout [11,12]. If the replacement of FFDM with DBT as the standard screening modality is to be feasible then reading times will need to be reduced. One suggestion is to process DBT images such that standard 1 mm image slices are combined into thicker slabs to reduce the number of images for review. This method can significantly reduce

reading time, but there's mixed findings when comparing diagnostic accuracy with conventional DBT, highlighting a potential drop in sensitivity with slab images [17,18]. Additionally, there's considerable scope to improve screening by employing artificial intelligence (AI) models that can independently read mammography images with performance comparable to human observers [19,20]. Retrospective studies have suggested that AI could be used as a triaging tool, removing the need to read some examinations flagged as normal, or as an independent reader in the double reading workflow reducing workload by at least half, without affecting the sensitivity and specificity of double reading [21–24]. In addition, decision support tools may also improve reading efficiency [25,26]. Conant et al. found that DBT reading time was reduced by 52.7 % when a DBT AI system was incorporated into the interpretation of DBT studies [25]. All these strategies have the potential to free up the additional reading time required to implement routine screening with DBT.

A significant difference was identified in reading time between DBT+S2D and DBT + FFDM, although the magnitude of difference on average was relatively small –12 s per case. The reason for this increase is unclear. It is possible that reading times were increased due to readers unfamiliarity with the use of the synthetic 2D image in the screening workflow. It is known that breast screening performance is maintained when synthetic mammography replaces a directly acquired digital mammogram in DBT image interpretation [27,28]. The reduction in radiation dose outweighs the relatively modest increase in reading time [27,29,30].

There is little evidence that DBT interpretation performance improves with reader experience [31,32], but our study suggests there is a learning curve effect when it comes to reading times. Readers with five or more years of experience had average reading times 31 s faster than those with less experience. Additionally, DBT reading time significantly reduced by an average of 22 s after less than 9 months of reading DBT in a screening setting, indicating that after a relatively short period of DBT implementation into a screening programme reading times can improve significantly. In the NHS breast screening programme, screening mammograms are read by radiologists and radiographer readers with no difference in diagnostic performance [33]. With 78 % of breast screening units in the UK employing at least one radiographer reader in a physician extender role, it is reassuring that our study also demonstrated no difference in reading times between readers from different professional groups [34].

Study limitations should be acknowledged. Firstly, data collection across the six breast screening centres was not uniform and this meant that about two thirds of the DBT reading time data were calculated from batches that contained a mixture of DBT and FFDM screening cases. Since the reading time data is derived from real-life practice, error may also have been introduced as a consequence of reading breaks, interruptions, slow workstations, etc. that were not contemporaneously noted by the reader. Secondly, the PROSPECTS Trial is ongoing and individual performance metrics for readers are not yet known. Ultimately it will be important to show that no decrease in reader performance is accompanied by the reduction observed in reading time. Thirdly, the early phase of the PROSPECTS Trial was interrupted by the COVID pandemic, which meant some readers were excluded when their first nine months of screening DBT reading experience fell within this period when screening was reduced or ceased. In addition, some readers and batches were excluded due to small numbers. Finally, the reading time data was acquired in a screening programme where double reading is the standard of care and so these results may not be applicable to readers in other settings.

In conclusion, it is important to consider logistics, particularly reading time, when introducing DBT into a national breast screening programme. Readers took twice as long to read DBT compared to FFDM, and also demonstrated increased reading times when DBT was read with synthetic mammography compared to DBT+FFDM. There was no difference in reading times between radiologists and radiographer readers in a programme that routinely utilises radiographers in the double reading workflow. Although DBT reading times were longer, a relatively short exposure to the modality of < 9 months led to a significant shortening of reading time. Comprehensively understanding DBT reading times in the breast screening setting is invaluable when making informed decisions to implement screening DBT.

5. Compliance with Ethical standards

1. ***Guarantor:***

   The scientific guarantor of this publication is Yan Chen.

2. ***Statistics and Biometry:***

   No complex statistical methods were necessary for this paper.

3. ***Informed Consent:***

   Only if the study is on human subjects:
   Written informed consent was obtained from patients.

4. ***Ethical Approval:***

   This study has undergone independent external review as part of the King's Research and Development protocol, and has been approved by the London – Dulwich Research Ethics Committee.

5. ***Study subjects or cohorts overlap:***

   N/A.

6. ***Methodology***

- prospective
- randomised controlled trial
- multicenter study

CRediT authorship contribution statement

George J. W. Partridge: Writing – review & editing, Writing – original draft, Software, Project administration, Methodology, Formal analysis, Data curation. **Iain Darker:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis. **Jonathan J. James:** Writing – review & editing, Writing – original draft, Supervision, Methodology. **Keshthra Satchithananda:** Writing – review & editing, Project administration, Data curation. **Nisha Sharma:** Writing – review & editing, Project administration, Data curation. **Alexandra Valencia:** Writing – review & editing, Project administration, Data curation. **William Teh:** Writing – review & editing, Project administration, Data curation. **Humaira Khan:** Writing – review & editing, Project administration, Data curation. **Elizabeth Muscat:** Writing – review & editing, Project administration, Data curation. **Michael J. Michell:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Yan Chen:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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