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SCIENTIFIC PAPER

Analysis of patient breast dose from a mammographic biopsy unit

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Abstract
Further assessment of suspicious lesions found during asymptomatic breast cancer screening is critical and involves mammographic follow up with biopsy. The X-ray procedure is complex and variable in nature and until now there is little information on the radiation dose to the breast or associated risks. A survey of radiation doses from a Siemens MammoTest prone biopsy with the support of a Sectra L30 AIR mammographic unit for workup and post clip images has been completed. Procedure details and outcomes, including radiographic and patient related variables have been collected and analysed using standard dosimetric formulation. The partial irradiation of the breast in biopsy and magnification views was considered. The average mean glandular breast dose was 5.13 mGy, comprising of 3.52 mGy from the biopsy procedure and 1.61 mGy from the workup and post clip images, with an average of 8.4 biopsy images and 5.8 workup and post clip images. The risk from these dose levels are dependent on the age of the woman, however are not considered high for a symptomatic X-ray procedure.

Keywords Mammographic dose · Biopsy · Mean glandular dose

Introduction

The detection and diagnosis of breast cancer has relied heavily on the use of X-ray breast screening which has been credited with a substantial decrease in breast cancer mortality through early detection [1, 2]. Critical in this process is the assessment of non-palpable, suspicious findings that require histologic evaluation. Such assessment is usually carried out using percutaneous breast biopsy techniques [3]. These biopsy techniques, involving the use of core biopsy needles or vacuum-assisted biopsy, require a high degree of diagnostic accuracy which can only be achieved by meticulous attention to technique and with multidisciplinary cooperation [4]. From a radiological perspective for a patient undergoing a stereoscopic biopsy assessment, the following steps generally may apply, subject to local protocol variations. (1) Standard mammographic work up images are taken in the region of the suspected lesion including the latero-medial, spot compression(s) and spot magnification views. (2) Biopsy assessment images, including a scout view and a stereo pair of images are taken to plan the biopsy procedure and to locate the region of interest. (3) Once the target position is determined a stereo pair is performed post local anaesthetic to ensure the calcium deposits and/or lesions are still located in the same coordinates. A repeat post-fire image could be performed prior to performing the biopsy. (4) Once the sample is taken calcification specimens are imaged separately to confirm the presence of calcifications, a surgical indicator clip is deployed followed by another stereo image pair. (5) Once the biopsy is completed the patient will undergo post clip full view breast mammography with two views, to indicate clip position relative to the full breast image.

The radiation dose to the breast from such procedures has not been widely studied, unlike the dose to the breast from X-ray screening examinations. This may be due to the symptomatic nature of the procedure which changes its justification status [5] compared to that of non-symptomatic X-ray screening examinations, or simply due to the complexity of the procedure. Established methods of dose estimation [6–8] can be applied to the estimation of the breast dose from a full biopsy procedure, however consideration of the exposed field size on the breast [9] and the possible multiple exposures involved in the examination need to be carefully considered. The current work reports on a survey of the mean glandular dose to patients undergoing assessment

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biopsy procedures associated with breast screening. The survey focusses mainly on the radiation dose from the biopsy process itself, however estimates are also made of mammographic dose for typical assessment work ups prior to biopsy and similarly post clip mammographic dose.

Methods

Equipment and dosimetric methods

The survey is based on records of 224 mammography biopsy procedures undertaken on a Siemens MammoTest prone biopsy unit utilising a Molybdenum target and filter system and a maximum tube potential of 35 kV. The radiographic exposure is initially performed with AEC at a selected kV as determined by the posted technique chart. If the exposure is thought satisfactory, the factors are then used to perform the remainder of the examination manually. This allows the exposures to be altered if the local injection or any small bleeds obscure the area of interest. The field of view at the aperture upon the breast was 5 cm × 5 cm. The unit was under annual quality control and equipment maintenance throughout the time of the survey.

Survey data was collected manually (see Fig. 1) for each patient including the nominal procedure kV and mAs, the number of exposures for the procedure, the breast size, compressed breast thickness as well as procedural indicators of the technical difficulty on a scale of 1–3, visibility of calcifications, calcifications seen in 2 projections and use of post clip projection. The clinical result of the biopsy were recorded as either, positive, negative, atypical lobular hyperplasia (ALH) or atypical ductal hyperplasia (ADH) or abandoned. Both ALH and ALH are not breast cancer, but are considered a precancerous condition. The study obtained ethics approval and data from 224 procedures was collected. The data was entered into an excel spreadsheet for analysis.

The determination of the breast mean glandular dose was achieved using the formalism of Wu [6] assuming a breast glandularity of 50% as further information was not available. The parameterisation of Sobel [10] for molybdenum target and filters was adopted allowing automated

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Sheet No.

BreastScreen ACT

Data from stereotactic vacuum assisted biopsies

No.	Client ID	Date	kV	mAs	# of exposures	Size of Breast*	Thickness of comp. breast	Tech difficulty (1,2 or 3)	Calc visibility**	Calc seen in 2 projec.? (Y/N)	Post clip projec.?	Result Pos/Neg
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												

*Size of Breast:
Very Small **(VS)**: Window on compression plate covers all of the breast
Small **(S)** : Window covers half of breast
Medium **(M)**: Window covers a third of the breast
Large **(L)**: Window covers a fifth of the breast
Extra Large **(EL)**: Window covers less than a fifth of the breast

**Calcification visibility:
1: Calcification is easily visible
2: Calcification - Powder
3: Not calcification (i.e. Density)

Comments: Please note any machine maintenance dates or other equipment related information.

Fig. 1 Template for the collection of biopsy data

calculation. Needed parameters such as actual tube voltage, incident air kerma to the breast and beam HVL values were determined from equipment quality assurance data through the use of linear relationships between quantities and calibration setup data. The resulting mean glandular dose was corrected to account for the reduced exposure field size by two approaches. The method advocated by the UK National Health Services Cancer Screening Programmes [9] is to multiply the calculated mean glandular dose by the ratio of the exposed field size and the surface area of the standard breast model. In this case that value is 25%. However a similar but an alternative approach is to use the ratio of the exposed field size and the actual breast size of the patient involved. This data was also applied to calculations through the breast sizes reported by the radiographer, where the sizes XS, S, M, L, XL corresponded to the multipliers of 1, 0.5, 0.3, 0.2 and 0.1 respectively. Further as only one breast is examined in a biopsy procedure the calculated mean glandular dose is divided by two as only half of the mass of glandular tissue is considered through this procedure.

Determination of the typical dose for the assessment work up images and the post clip films was simplified by the fact that all women were imaged on a single type of mammography unit being a Sectra L30 AIR mammographic unit. Thirty-five radiographs of a sample of six women undergoing assessment associated with biopsy cases from the survey cohort were reviewed to establish typical mean glandular doses for both work up and post clip images. The parameters gathered were the kV, mAs and breast thickness. For the magnification views used in work ups an approximate estimate of the percent of breast volume irradiated for the mag mode was calculated using the diameter of spot film compression paddle (90 mm) and the estimated breast size established in the biopsy data set, taking into consideration additionally the lateral displacement of tissue in the mag mode informed by considering the compression thicknesses for mag and biopsy modes. On the Sectra units the magnification mode in fact uses collimated contact images taken with increased mAs and is electronically magnified. This simplified semi empirical estimation of mean glandular dose does not include any scatter contribution to the non directly exposed breast during a magnification exposure. Sarno et al. [11] have recently shown that under specific conditions such a simplification can give an underestimation of 7% when compared to analysis using Monte Carlo simulations. The dosimetry method, again assuming a 50% glandularity, followed the formulation of Dance [12] allowing automated calculation for tungsten target units. Differences in MGD calculation when comparing the dose formalisms of Dance and Wu under similar conditions have been noted by Klein [13], attributed to differences in the superficial adipose layer thickness in the models used, differences in cross-section data, compression plates and the spectra used. These effects are modest (within 15%) and Klein has also noted that use of the 50% glandularity model can result in variations of up to 15% when compared to calculations using actual patient glandularity.

The correlation of total mean glandular dose with recorded variables was analysed using regression analysis, while the mean values of recorded parameters were also compared for the different procedure results.

Table 1 Summary statistics of radiographic factors and breast size for 244 recorded cases of biopsy examinations*

	kV	mAs	Number of exposures	Breast thickness (cm)	Fraction of breast irradiated
Mean	28.7	170.8	8.5	5.6	0.31
Max	31.0	600.0	23.0	10.5	1.00
Min	25.0	40.0	3.0	1.0	0.10
Stdev	1.0	84.8	2.7	1.5	0.14

*Max and min values are for differing patient records

Table 2 Summary statistics of single and cumulative doses for 244 recorded cases using two methods of determination

	Dg single exposure[a]	Dg single exposure[b]	Dg cummulative[a]	Dg cummulative[b]
Mean	0.34	0.42	2.89	3.52
Max	1.11	2.51	13.60	18.13
Min	0.10	0.06	0.34	0.27
Stdev	0.16	0.30	1.75	2.70

[a]Calculated mean glandular dose modified using a standard correction factor of 0.25

[b]Calculated mean glandular dose modified using a patient specific correction factor

Results

The average and range of radiographic factors used for the 244 breast biopsies is given in Table 1 with Table 2 giving the average and mean glandular dose range for patient doses estimated using a fixed correction factor and a breast specific correction factor. An analysis of radiographic factors showed a weak correlation between breast thickness and tube potential ($R^2 = 0.23$) and breast thickness and tube current ($R^2 = 0.32$). There was no correlation between the number of exposures and breast thickness, however there was a more substantial correlation between the fraction of breast irradiated and breast thickness ($R^2 = 0.42$) as seen in Fig. 2. While there is only a very weak correlation between the breast thickness and mean glandular dose to the breast as seen in Fig. 3 ($R^2 = 0.11$), there is, as intuitively expected, a clear difference in the mean glandular

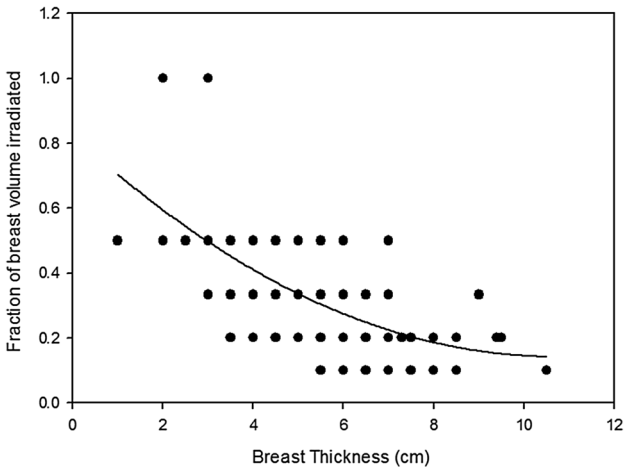

Fig. 2 Relationship between the patient breast thickness and the estimated percentage of irradiation breast tissue

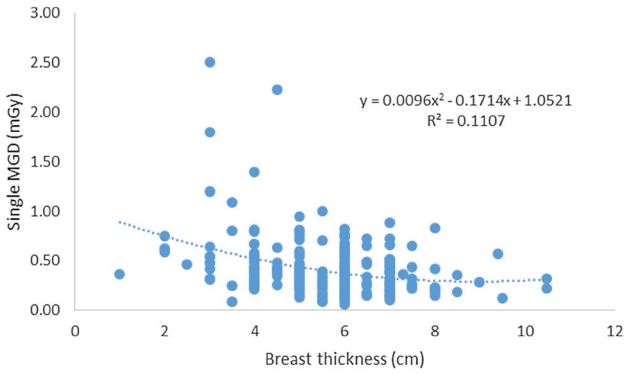

Fig. 3 The mean glandular dose for one exposure as estimated using a patient specific area correction factor as a function of breast thickness

dose distribution as a function of breast size, between the methods used to correct breast dose for partial irradiation as seen in Figs. 4 and 5. The cumulative dose to biopsy patients is shown in Fig. 6.

The correlation between total mean glandular dose from biopsy procedures and associated variables was generally weak, with the correlation of dose and fraction of breast irradiated being the strongest ($r^2 = 0.37$). There was also a correlation ($r^2 = 0.22$) between dose and the number of exposures during the biopsy. Factors such as breast thickness, the calcification index and the technical difficulty index had very weak correlations with mean glandular dose. The differences in mean parameter values for different procedure outcomes are seen in Tables 3 and 4.

Tables 5 and 6 display the results of the analysis of six patients including the dose assessments for work up and post clip images and the relationship of this dose to the biopsy procedure dose.

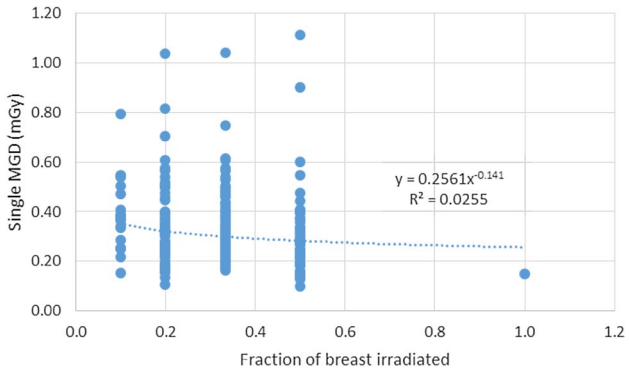

Fig. 4 The mean glandular dose for one exposure as estimated using the fixed area correction factor of 0.25 as a function of the fraction of breast volume irradiated

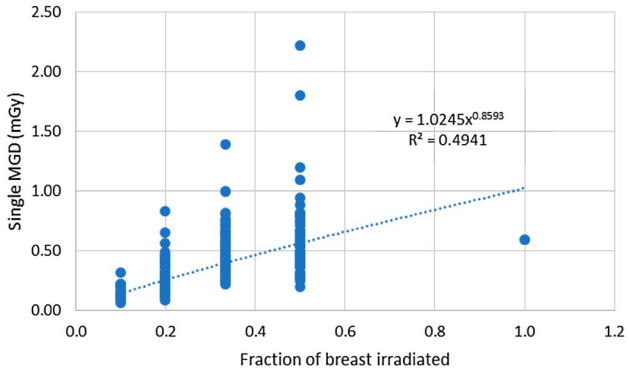

Fig. 5 The mean glandular dose for one exposure as estimated using a patient specific area correction factor as a function of the fraction of breast volume irradiated

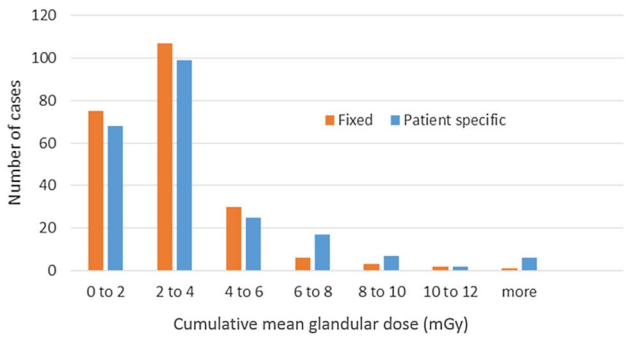

Fig. 6 Histogram of number of patient cases against binned cumulative mean glandular dose (mGy) using both a fixed and patient specific irradiation area correction factor

Discussion

It is seen for the sample of women studied that the estimated average correction factor, corresponding to the typical fraction of breast volume irradiated was 0.32 compared

Table 3 Summary of procedure results in terms of exposure and patient parameters

Procedure result	% of total	Mean number of exposures	Mean breast thickness (cm)	Mean fraction of breast irradiated	Mean Dg cummulative[a]
All	100	8.4	5.6	0.31	3.52
Positive	34	9.1	5.7	0.30	3.84
Negative	59	8.2	5.6	0.31	3.24
ADH/ALH	4	9.1	5.1	0.36	3.6
Abandoned	3	4.6	4.9	0.40	3.77

[a]Calculated mean glandular dose modified using a patient specific correction factor

Table 4 Summary of procedure results in terms of procedural parameters

Procedure result	% of total	Mean technical difficulty	Mean calc index[a]	% calc seen	% post clip
All	100	1.4	1.3	92	89
Positive	34	1.4	1.1	93	87
Negative	59	1.3	1.3	93	93
ADH/ALH	4	1.1	1.3	88	100
Abandoned	3	2.7	2.4	29	0

[a]1 calcification is easily visible, 2 calcification—powder, 3 not calcification (i.e. density)

Table 5 Dosimetry for 6 patients undergoing magnification/non magnification view for workup and post clip images with a Sectra L30 unit

Patient	Magnification view	Number of images	Mean kV	Mean mAs	Mean breast thickness (mm)	% breast irradiated	Total MGD (mGy)
1	Y	3	29	29	39.7	28	0.50
	N	2	29	10.5	48	100	0.35
2	Y	2	29	39.5	48.5	71	0.93
	N	3	32	13.3	54	100	0.77
3	Y	3	29	39.3	49.3	47	0.91
	N	4	32	13.3	58.8	100	1.11
4	Y	2	30.5	51	63.5	28	0.46
	N	3	32	18	74	100	0.91
5	Y	2	29	39	49	47	0.61
	N	3	31	17.3	58	100	0.96
6	Y	5	30.8	54.6	67.8	28	1.21
	N	3	32	19	75	100	0.94
Average	Y	2.8	29.6	42.1	53.0	41.5	0.77
	N	3.0	31.3	15.2	61.3	100.0	0.84

to the 0.25 recommended in UK documents. Further when comparing Figs. 4 and 5 a better correspondence between glandular dose and fraction of breast tissue irradiated clearly demonstrates the superiority of patient specific correction factors for partial irradiation. Further it is seen that the total dose from the biopsy procedure is very variable with no clear correlation on a particular variable. The dose contribution from patient work up shows much less variance, from a sample of six patients a mean glandular dose of 1.06 mGy was determined, with 0.55 mGy for post clip images. This is significantly different to the biopsy average of 4.28 mGy for the six patients, which can be compared to an average biopsy dose for the whole survey of 3.52 mGy. Even in the case of a large biopsy dose as with patient 5, the additional contribution from workup and post clip images remained at the average value discussed above. In summary it would seem that an average total dose for an assessment involving biopsy might be approximately 5 mGy using the equipment described, with the highest dose being in the order of 20 mGy.

The detriment attributed to radiation dose will depend substantially on the age of the woman undergoing

Table 6 Summary of partition of dose components for full biopsy assessment for 6 patients

Patient	Total work up MGD (mGy)	Total post clip MGD (mGy)	Total biopsy MGD (mGy)	% biopsy to total MGD (%)
1	0.67	0.18	1.54	64
2	1.15	0.54	4.82	74
3	1.46	0.57	2.44	55
4	0.74	0.63	2.16	61
5	0.83	0.74	14.2	87
6	1.51	0.65	0.5	19
Average	1.06	0.55	4.28	60

Table 7 Risk of cancer incidence per 100,000 cases as a function of age for the average and maximum breast dose from the survey

Age of woman	5 mGy	20 mGy
20	21	86
30	13	51
40	7.1	28
50	3.5	14
60	1.6	6.2
70	0.6	2.4

mammography. An estimation of the risk of cancer incidence [14] is shown in Table 7. For a 50 year old woman with an average glandular dose of 5 mGy there is an expected incident cancer risk of 3.5 cases in 100,000. When this is viewed against the 40% chance of a non-negative outcome from the biopsy (Tables 3, 4) it is clear that the radiation risk can be viewed as negligible for the procedure.

Conclusions and future work

A dosimetric assessment for a cohort of women undergoing biopsy as part of a recall breast screen assessment has been determined for specific radiographic equipment. The results indicate that an average dose of about 5 mGy is a reasonable assessment, inclusive of workup and post clip images, with a possible maximum dose of 20 mGy. While this dose is higher than an average mean glandular dose of 3.7 mGy for digital mammography, as quoted by Hendrick [2], or the 2 mGy that might be expected from the Sectra equipment used for this work, it needs to be considered that assessment dose is for symptomatic patients where the probability of cancer detection is very much higher than for non-symptomatic patients.

It should further be stressed that the dose results determined above are equipment specific and that other mammographic systems may deliver significantly different dose levels. Recently ACT BreastScreen has moved to new equipment and techniques that include the use of digital tomosynthesis as part of the assessment workup. Investigation into the dosimetric impact of this new approach is ongoing and should give important information for the optimisation of exposure techniques to be consistent with good radiation hygiene.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Institutional ethics approval was obtained: ethlr.13.258 "Estimation of subject breast dose from mammographic stereotactic vacuum assisted biopsies".

Informed consent For this type of study formal consent is not required. This article does not contain any studies with animals performed by any of the authors.

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