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FULL PAPER

Contrast enhanced digital mammography versus magnetic resonance imaging for accurate measurement of the size of breast cancer

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Objective: To compare the accuracy of contrast-enhanced digital mammography (CEDM) and MRI, including maximal intensity projection (MIP) images, for measuring the tumour size of breast cancer.

Methods: We included 52 females (mean age, 50.9 years) with surgery due to breast cancer, and measured maximum diameter of main mass on mediolateral oblique (MLO) and craniocaudal (CC) views of mammography and CEDM; sagittal, axial MIP images, and early dynamic contrast-enhanced MRI (CEMRI) before surgery. Bland-Altman plot, intraclass correlation coefficient, and univariate linear regression analysis were used to evaluate the maximum size between imaging and pathology including only invasive component ($OP_{invasive}$) or with carcinoma *in situ* (OP_{max}).

Results: Mean $OP_{invasive}$ was 15.5 mm, and overestimation rate was similar or higher than underestimation rate on

all images except CC view of mammography and axial MIP image of CEDM. Mean OP_{max} was 21.7 mm, and underestimation rate was higher than the overestimation rate. All parameters of CEDM and CEMRI showed good agreement ($k > 0.75$) with $OP_{invasive}$, with the most favourable result being the CC view of CEDM and axial MIP image of CEMRI.

Conclusion: All views of CEDM and MRI provided accurate measurements of tumour size. Axial plane CEDM and MRI would be the first choice for image review and treatment planning, with the highest accuracy obtained by using CC view of CEDM.

Advances in knowledge: Previous studies have not compared the measurement of the tumour size using detailed sequences; in our study, we discovered that CEDM can be an alternative modality to CEMRI.

INTRODUCTION

The primary role of pre-operative breast imaging is to determine the extent of disease and to aid in its accurate diagnosis. The accurate pre-operative measurement of tumour size in breast cancer patients is crucial in planning surgery with or without neoadjuvant chemotherapy, as well as evaluating the disease prognosis based on T staging.^{1,2} MRI is considered the most accurate and widely used modality for the preoperative evaluation of breast cancer.³ Of the different sequences of MRI, Choi et al reported that the maximal intensity projection (MIP) image was the most accurate sequence to measure tumour size.⁴ The view provided by the MIP image is the most similar to that provided by mammography (MG); thus, it would be easier to use compared with MG.

MG is the primary imaging modality for breast screening, and along with the development of digital mammography, contrast-enhanced digital mammography (CEDM) was recently introduced in order to improve the diagnostic accuracy in the detection of breast cancer.⁵ Dual-energy subtraction technique is used in CEDM after the intravenous injection of contrast dye, and angiogenesis of the breast cancer is detected by the uptake of contrast media, which is similar in principle to contrast-enhanced MRI (CEMRI).

Previous studies have compared the diagnostic performance of CEDM and CEMRI, with commensurate positive outcomes of accuracy in both techniques.^{6,7} Furthermore, several studies have proposed that CEDM may be used as an alternative to CEMRI to accurately predict the size of the tumour.⁸⁻¹¹ However, to the best of our knowledge,

previous studies have not compared or described the measurement of tumour size using detailed sequences or evaluated parameters other than the MIP image of CEMRI.^{8–11}

The purpose of the present study was to compare the accuracy of CEDM and CEMRI, including MIP images, in the measurement of sizes of histologically proven breast cancers; this would help to provide more precise information for surgeons.

METHODS AND MATERIALS

This prospective study was approved by our institutional board (KBSMC 2016-08-016) in accordance with the Declaration of Helsinki. All patients provided written informed consent.

Patients

Between November 2016 and March 2017, 130 females who underwent CEMRI, before planned surgery for breast cancer at Kangbuk Samsung Hospital, were considered for this study. The exclusion criteria were as follows: (1) contraindications to iodinated contrast agent or impaired renal function due to chronic renal disease according to the guidelines of the Korean Society of Radiology;¹² (2) administration of any contrast material within 24 h prior to the CEDM; (3) history of diabetes mellitus, implants, or prior confirmation of diagnosis by stereotactic biopsy or mammotome biopsy. Subsequently, in consensus with the surgeon, 52 females with 54 cases of breast cancer underwent CEDM before the surgery within a week before the surgery.

Radiologic and histopathological analysis

In patients who had not undergone any recent MG, the initial mammographic studies were performed with standard craniocaudal (CC) and mediolateral oblique (MLO) views on a full field digital mammography unit (*Lorad Selenia*, Hologic, Danbury). The patients underwent breast ultrasound scans (*Philips iU22 platform*, Philips Healthcare, Bothell; *Aixplorer*, SuperSonic Imagine, Aix-en-Provence, France) and ultrasound-guided core needle biopsies for suspicious lesions; the latter was performed with a 14-gauge needle and an automated biopsy gun (Promac 2.2; Manan Medical Products, Northbrook, IL) or a TSK Stericut (Standard type with Co-axi; TSK Laboratory, Tochigi, Japan).

After confirming the malignancy, CEMRI was performed in the prone position, using a 3.0 T system (*Achieva*, Philips Medical System, Best, Netherlands) with a dedicated 7-channel SENSE breast coil. The following images were acquired after obtaining the localizer images: T_2 weighted (W) turbo spin echo axial images (repetition time (TR)/echo time (TE), 3790/100; 332 × 316 matrix; field of view (FOV), 200 × 340 mm; slice thickness, 3 mm; gap, 1 mm), T_1 W turbo spin echo axial images (TR/TE, 620/10; 332 × 332 matrix; FOV, 200 × 340 mm; slice thickness, 3 mm; gap, 1 mm), dynamic CE examination using a fat-suppressed T_1 W three-dimensional fast field echo sequence (TR/TE, 7.0/3.5; 452 × 410 matrix; FOV, 340 × 340 mm; slice thickness, 2 mm; no gap), and delayed axial T_1 W spin echo images (TR/TE, 532/10; 448 × 378 matrix; FOV, 380 × 380 mm; slice thickness, 5 mm; gap, 2.5 mm). Six series of axial dynamic CEMRI for both breasts were obtained at 0, 1, 2, 3, 5, and 7 min after the intravenous injection of 1.0 M gadobutrol (7.5 ml Gadovist;

Figure 1. Timeline for contrast-enhanced digital mammography. The diagram shows the sequence of steps. First, the contrast medium was injected. After 2 min of injection, the patient was positioned, and the images are acquired from the MLO and CC view of the target breast, as well as the CC and MLO view of the non-target breast. CC, craniocaudal; MLO, mediolateral oblique.

Bayer Schering Pharma, Berlin, Germany). Under the post-processing, the MIP images for sagittal and axial views were also obtained using dynamic CEMRI at 3 min after the injection of contrast dye.

All CEDM examinations were performed with a digital mammography device; this allowed dual-energy acquisition (*Selenia Dimensions*[®], Hologic, Bedford, MA) within 30 days of CEMRI. An intravenous injection of Omnipaque 350 (GE Healthcare; 1.5 mL/kg of body weight with a flow rate of 2 mL/s using power injector) was administered through an 18-gauge needle without compression of the breast. Approximately 2 min after injection, the patient was positioned for CEDM with serial pairs of low- (Rh or Ag filtration, using a kVp between 26 and 32), and high-energy (Cu filtration, using a kVp of 49) images for both breasts under one compression within 5 min; thus, the total imaging time was within 7 min from injection of the contrast dye. The low-energy acquisition was post-processed to obtain an image similar to that of a conventional mammography unit. The target breast was defined as the side-containing a proven malignancy, and the non-target breast as the opposite side. The order of images has been summarised in Figure 1: from the MLO and CC view of the target breast, as well as the CC and MLO view of the non-target breast. Using post-processing I-view software[®] (Hologic, Bedford, MA), the subtracted images of the low- and high-energy acquisitions were obtained to emphasize the enhancement of injected iodine.

The visibility of the main lesion was defined as the presence of only visible enhancement within the malignancy on the MLO view, CC view of conventional MG and CEDM, axial and sagittal MIP image, and fat-suppressed axial T_1 W dynamic CEMRI at 1 min after contrast injection (DCE_{1min}). The other enhancing lesions in the cases with multifocal or multicentric breast cancer were not considered in this study. Two radiologists (IY and SHK) blindly reviewed all images and evaluated the visibility of the tumour on each image of the CEDM and CEMRI.

One radiologist (IY) measured the maximum diameter of the main lesion including microcalcifications, masses, or architectural distortions on the MLO, CC view of MG, and enhancing main lesion on MLO and CC views of CEDM without considering

Figure 2. A 52-year-old female with surgically confirmed invasive ductal carcinoma in the right breast. She underwent contrast-enhanced digital mammography before surgery, and the enhancing proven malignancy was found on the mediolateral oblique (a, 10.6 mm) and craniocaudal (b, 10.9 mm) views. On MRI, the enhancing proven malignancy was also found in the sagittal (c, 13.4 mm), axial (d, 6.9 mm), maximum intensity projection images, and fat-suppressed axial T_1W dynamic CEMRI of 1 min after contrast injection (e, 10.0 mm). The calculated maximum diameter of the contrast-enhanced digital mammography and the maximum intensity projection image of MRI was 10.9 mm and 13.4 mm, respectively. She underwent breast-conserving surgery on the right side, and the maximum diameter including only the invasive component, and both of invasive cancer and carcinoma *in situ* were the same value, measuring up to 12 mm. CEMRI, contrast-enhanced MRI.

microcalcifications or other findings, and sagittal, axial MIP reconstructions, subtracted DCE_{1min} of CEMRI (Figure 2). The maximum diameter of MG (Max_{mg} ; either MLO or CC view), CEDM (Max_{cedm} ; either MLO or CC view), and MIP reconstruction (Max_{mip} ; either sagittal or axial image) of CEMRI were calculated. Final histopathology results were reviewed, and the type of tumour and surgery were recorded. The maximum diameter including the invasive component ($OP_{invasive}$) alone, or both invasive cancer and carcinoma *in situ* (OP_{max}), were recorded through a post-surgical histopathology report.

Statistical analysis

Categorical data were summarized as frequencies and percentages. All calculations were performed using STATA 15.1 (StataCorp LP, TX). The tumour visibility on each combined image of the CEDM and MRI were compared using Fischer's exact test.

Mean values of predicted tumour size on MLO, CC views of MG and CEDM, Max_{mg} , Max_{cedm} , and sagittal, axial MIP images, Max_{mip} , and DCE_{1min} were calculated. Concordance between the predicted tumour size by MG, CEDM, MRI and pathologic size was defined as a difference of ≤ 5 mm; whereas below or above 5 mm was categorized as underestimation or overestimation.¹³

Bland–Altman plot¹⁴ was used to demonstrate the extent of the difference in the measurements between imaging and pathologic size of $OP_{invasive}$ and OP_{max} . The difference was plotted against the average of the two measurements. Agreements between MG, CEDM, CEMRI, and pathologic size of $OP_{invasive}$ and OP_{max} were analyzed using intraclass correlation coefficients (ICCs).¹⁵ An ICC > 0.75 was considered as a good agreement. For predicting

the $OP_{invasive}$ and OP_{max} , univariate linear regression analysis was performed using each method of MG, CEDM, and CEMRI. The β value is the regression coefficient that corresponds to the slope of the linear relationship, and the R^2 is the coefficient of determination.

RESULTS

The mean age of the included patients was 50.9 ± 9.6 years (range, 28–72 years). No patient complained of side-effects related to the injection of contrast media of CEDM and CEMRI. Among the 54 breast cancers, breast-conserving surgery was performed in 41 breasts, and the remaining 13 underwent a mastectomy. Of two patients with bilateral breast cancer, one underwent a bilateral mastectomy, and the other underwent bilateral breast-conserving surgery. The final histopathology results were as follows: invasive ductal carcinoma (IDC, $n = 40$), ductal carcinoma *in situ* (DCIS, $n = 7$), invasive lobular carcinoma (ILC, $n = 4$), and other pathology ($n = 3$; metaplastic squamous carcinoma, mucinous carcinoma, and tubular carcinoma).

The visibility of MG was slightly higher on the MLO view (40/54, 74.1%) than CC view (37/54, 68.5%). 35 cases were visible in all views, 7 IDCs were visible in either MLO or CC view, and 12 cases were invisible (8 IDC, 3 DCIS, and 1 ILC; mean OP_{max} , 16.8 ± 11.0 mm) on both MLO and CC views. On the CEDM, the MLO (48/54, 88.9%) and CC (47/54, 87.0%) views showed similar visibility which was much higher than that of MG. 45 cases were visible in all views; 5 cases (4 IDC and 1 ILC) were visible in either MLO or CC view; and 4 cases (1 IDC, 2 DCIS, and 1 mucinous carcinoma; mean OP_{max} , 19.5 ± 13.0 mm) were invisible on both MLO and CC views. However, the sagittal MIP (51/54, 94.4%), axial MIP (50/54, 92.6%), and DCE_{1min} (51/54,

94.4%) of CEMRI showed similar visibility (92.6–94.4%). 50 cases were visible in all images, and 2 cases were visible in at least one image; these were mucinous carcinoma, which was visible in only DCE_{1min} (OP_{max} 35 mm), and ILC, which was only visible in the sagittal MIP image (OP_{max} 12 mm). There were two invisible cases on all sequences, which were also invisible on the CEDM; one with IDC (OP_{max} 12 mm), and the other one with DCIS (OP_{max} 25 mm). The overall visibility of MG (77.8%, 42/54) was significantly lower than CEDM (92.6%, 50/54, $p = 0.030$) and CEMRI (96.3%, 52/54, $p = 0.004$). However, there was no statistically significant difference between the visibility of CEDM and CEMRI ($p > 0.05$).

For evaluating OP_{invasive}, the seven cases of DCIS were excluded, and the total number of cases for size comparison was changed as follows: (1) 36 MLO view, 32 CC view, and 38 Max_{mg} of MG; (2) 43 MLO view, 41 CC view and 45 Max_{cedm} of CEDM; (3) 45 sagittal MIP, 44 axial MIP, 45 Max_{mip}, and (4) 45 DCE_{1min} of CEMRI. The mean pathologic size of OP_{invasive} was 15.5 ± 14.1 mm (range, 0.9–85 mm; $n = 47$) on the final histopathology report. Subsequently, the mean size and concordance with OP_{invasive} of the MG, CEDM, and MRI are summarized in Table 1.

The highest concordance rate was found on the CC view of MG (46.9%), CEDM (65.9%) and axial MIP image of CEMRI (75.0%). Overestimation was frequently observed than underestimation when using the MLO view (33.3% vs 22.2%), Max_{mg} (34.2% vs 26.3%) of MG; MLO view (23.3% vs 14.0%), Max_{cedm} (22.2% vs 13.3%) of CEDM; sagittal MIP (17.8% vs 15.6%), and Max_{mip} (17.8% vs 13.3%) of CEMRI. Furthermore, CC view of MG (31.3% vs 21.9%) and axial MIP image of CEMRI (18.2% vs 6.8%) showed a higher underestimation rate than overestimation rate; however, on the CC view of CEDM, the rates of overestimation and underestimation were same (17.1%).

Figure 3 demonstrates the difference in measurements between imaging and OP_{invasive}. The difference in the size of OP_{invasive} in MG was 2.49 mm [95% confidence interval (CI), (–2.35 to 6.22 mm)], 0.944 mm [95% CI (–3.27 to 5.15 mm)], and 3.08 mm [95% CI (–0.61 to 6.77 mm)] on the MLO, CC view, and Max_{mg}, respectively. The difference in size of OP_{invasive} in CEDM was 2.19 mm [95% CI (–0.49 to 4.86 mm)], 0.76 mm [95% CI (–1.50 to 3.01 mm)], and 2.52 mm [95% CI (0.16 to 4.89 mm)] on the MLO, CC view, and Max_{cedm}, respectively. With regard to CEMRI, the difference was 1.90 mm [95% CI (–0.73 to 4.52 mm)], –0.51 mm [95% CI (–2.84 to 1.82 mm)], 2.45 mm [95% CI (–0.03 to 4.92 mm)] and –0.04 mm [95% CI (–2.38 to 2.30 mm)] on the sagittal MIP, axial MIP, Max_{mip}, and DCE_{1min}, respectively. Mean OP_{invasive} showed good agreement with all parameters of MG, CEDM, and CEMRI (ICC > 0.75, Table 2). The highest ICC value was observed on the CC view of MG [$k = 0.820$; 95% CI (0.631–0.912)], CEDM [$k = 0.907$; 95% CI (0.825–0.950)] and axial MIP image of CEMRI [$k = 0.917$; 95% CI (0.844–0.956)]. Linear regression analysis demonstrated a significantly positive correlation between imaging and OP_{invasive} ($p < 0.001$, Table 1). Additionally, the highest R² value was also noted in both CC view of MG (0.489), CEDM (0.746), and axial MIP image of CEMRI (0.693).

The mean size of OP_{max} was 21.7 ± 14.8 mm (range, 6–85 mm; $n = 54$) on the final histopathology report. Table 2 and Figure 4 demonstrate the results of OP_{max}. The highest concordance rate was found on the CC view of MG (44.4%), CEDM (56.5%) and DCE_{1min} for OP_{max} (62.8%). The underestimation rate was higher in all images of the MG, CEDM, and CEMRI. The difference in measurements between imaging was as follows (Figure 4): –1.61 mm [95% CI (–5.66 to 2.44 mm)], –2.83 mm [95% CI (–7.29 to 1.64 mm)], –0.97 mm [95% CI (–5.03 to 3.08 mm)] on MLO view, CC view, Max_{mg} of MG; –2.03 mm [95% CI (–4.99 to 0.92 mm)], –2.11 mm [95% CI (–4.70 to 0.48 mm)], –0.97 mm [95% CI (–3.70 to 1.76 mm)] on MLO view, CC view, Max_{cedm} of CEDM; –1.83 mm [95% CI (–4.77 to 1.11 mm)], –4.07 mm [95% CI (–6.70 to –1.44 mm)], –1.12 mm [95% CI (–3.85 to 1.61 mm)], –3.53 mm [95% CI (–6.19 to –0.87 mm)] on sagittal MIP, axial MIP, Max_{mip}, and DCE_{1min}. Good agreement (ICC > 0.75, Table 2) between all values of CEDM and CEMRI were observed except MG (range of ICC, 0.733–0.750). Of CEDM and CEMRI, the highest ICC and R² values were seen on CC view [$k = 0.863$; 95% CI (0.752–0.924); R² = 0.670] and axial MIP image [$k = 0.884$; 95% CI (0.791–0.913); R² = 0.635].

DISCUSSION

Breast MRI is an important imaging modality for breast cancer patients; however, the high-cost of the procedure, claustrophobia, longer study time, and lesser accessibility with few contraindications compared with MG are a few of its limitations.^{8–11,11,16} Based on the results of previous studies, the present study hypothesised that the accuracy of CEDM for the detection of lesions would be comparable to that of CEMRI, owing to a similar physiology of contrast-enhancement.^{7,9,10} Consequently, we evaluated the results of MG for the baseline comparison to CEDM and CEMRI. Our study showed significantly higher visibility on CEDM and CEMRI than MG. Additionally, approximately 90% of cancers were detected using CEDM, which was marginally lower than MRI, without statistical significance. The visibility was enhanced by 93–96% when the definition is changed to the case where it is seen from any one image. The visibility of the tumour was superior using CEDM compared to full-field digital mammography or digital tomosynthesis for ultrasound-detected breast cancers, which was consistent with previous studies.^{6,7,9,10,17}

Breast MRI has been shown to be the most accurate modality for determining the extent of tumour especially in invasive breast cancers; however, overestimation or underestimation of tumour size may occur.^{4,18} Underestimation may increase the risk of residual cancer after surgery, while overestimation induces unnecessary mastectomy rates; thus, it is important to utilise imaging to predict the accurate tumour size prior to surgery. Although CEDM is a recent preoperative imaging modality, the principle is similar to CEMRI. To the best of our knowledge, no studies have compared each view of CEDM with different sequences of MRI.

Accurate measurements of CEDM and CEMRI could be limited by background parenchymal enhancement, the biology of the

Table 1. Measured mean size, concordance, and linear regression of MG, CEDM, and CEMRI with its agreement of maximum tumour size including only invasive components

	MG			CEDM			CEMRI			
	MLO	CC	Max _{mg}	MLO	CC	Max _{cedm}	Sagittal MIP	Axial MIP	Max _{mip}	DCE _{1min}
Mean size (range, mm)	21.1 ± 11.9 (6.5–73.2)	21.2 ± 13.3 (6.2–76.9)	22.1 ± 12.6 (6.7–76.9)	20.3 ± 10.9 (6.6–59.2)	20.0 ± 11.8 (6.4–66.9)	20.9 ± 11.9 (6.6–66.9)	19.8 ± 10.9 (6.6–58.8)	17.7 ± 10.8 (6.3–62.2)	20.5 ± 11.3 (6.6–62.2)	18.5 ± 11.6 (6.0–61.0)
Concordance										
Under estimation (%)	8 (22.2)	10 (31.3)	10 (26.3)	6 (14.0)	7 (17.1)	6 (13.3)	7 (15.6)	8 (18.2)	6 (13.3)	6 (13.3)
Concordance (%)	16 (44.4)	15 (46.9)	15 (39.5)	27 (62.8)	27 (65.9)	29 (64.4)	30 (66.7)	33 (75.0)	31 (68.9)	33 (73.3)
Over estimation (%)	12 (33.3)	7 (21.9)	13 (34.2)	10 (23.3)	7 (17.1)	10 (22.2)	8 (17.8)	2 (6.8)	8 (17.8)	6 (13.3)
Total	36	32	38	43	41	45	45	44	45	45
ICC (95% CI)	0.806 (0.620–0.901)	0.820 (0.631–0.912)	0.807 (0.629–0.900)	0.866 (0.753–0.927)	0.907 (0.825–0.950)	0.895 (0.809–0.942)	0.894 (0.807–0.942)	0.917 (0.844–0.956)	0.879 (0.781–0.934)	0.859 (0.743–0.922)
Linear regression analysis										
β (95% CI)	0.831 (0.525–1.137)	0.789 (0.488–1.089)	0.767 (0.489–1.045)	0.972 (0.728–1.217)	1.055 (0.856–1.255)	0.950 (0.746–1.155)	0.957 (0.713–1.201)	1.060 (0.841–1.280)	0.966 (0.742–1.189)	0.985 (0.780–1.190)
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
R ²	0.473	0.489	0.465	0.611	0.746	0.671	0.593	0.693	0.638	0.687

CC, craniocaudal; CEDM, contrast enhanced digital mammography; CEMRI, contrast enhanced magnetic resonance imaging; CI, confidence interval; DCE_{1min}, dynamic CEMRI at 1 min after contrast injection; ICC, intraclass correlation coefficients; MG, conventional mammography; MIP, maximal intensity projection; MLO, mediolateral oblique.

Figure 3. Bland–Altman plots for (a) MLO, (b) CC view, (c) MAX of MG; (d) MLO, (e) CC view, (f) MAX of CEDM; (g) sagittal, (h) axial, (i) MAX of MIP, and (j) fat-suppressed axial T1-W DCE_{1min} between the maximum diameter including the invasive component only (OP_{invasive}) on pathology. CC, craniocaudal; CEDM, contrast-enhanced digital mammography; CEMRI, contrast-enhanced magnetic resonance imaging; DCE_{1min}, dynamic CEMRI at 1 min after contrast injection; MAX, maximum size; MG, conventional mammography; MIP, maximal intensity projection; MLO, mediolateral oblique.

tumour, and the anthropological character of patients.^{19,20} Scattered radiation may also be an influencing factor in the inaccurate results of CEDM.¹⁹ Lobbes et al reported that CEMRI overestimated the size of tumours when compared to CEDM (2.12 vs 0.03 mm).²¹ However, other studies reported that both CEDM and CEMRI tend to lead to a slight overestimation of tumour size,^{19,20,22–26} similar to the results of the present study. Overestimation of tumour size can be explained by the differences in vascularization of the tumour and the surrounding precancerous tissue.¹⁹

Underestimation of OP_{max} in the present study using CEDM and CEMRI would be not significant for the patients' T staging because it only measured the extent of the invasive component; thus, it would not be useful to determine the prognosis. Previous studies reported the concordance rate of 47.1–76.5%^{20,22} and 53.0–68.3%^{4,13} of CEDM and CEMRI, respectively; with tumour size including the *in situ* component. Studies also reported no significant influence of additional extensive *in situ* component on tumour size measurement using CEDM and CEMRI.^{4,19} DCIS itself may be the strongest independent predictor of size discrepancy between pathology and imaging.⁴

In our result of OP_{invasive}, all views of the MG and CEDM showed more overestimation than underestimation, except both of CC views. It was the same in sagittal MIP image and Max_{mip} of CEMRI except for the axial MIP image and

DCE_{1min}. Overestimations were found more frequently on the images of the sagittal plane with MG, CEDM, and MIP images than axial images. Max_{mg}, Max_{cedm}, and Max_{mip} were calculated values, but they showed no significant power for accurate tumour size measurement. No studies have reported the best view of CEDM for the measurement of tumour size. Our results showed lower rates of concordance, ICC, and the R² value of linear regression analysis on all parameters of MG than those of CEDM and CEMRI. The result of CC view of CEDM and axial MIP image of CEMRI showed the highest ICC value, and the highest R² value was found on CC view (0.746 for OP_{invasive}; 0.670 for OP_{max}) than on all views of the CEDM and CEMRI. Choi et al reported that the MIP image of CEMRI was most accurate for the measurement of tumour size; this was concordant with our results, especially the axial MIP image.⁴ The results of the present study suggested that the images of axial plane CEDM and CEMRI accurately depicted the size of the tumour than those of the sagittal plane. Additionally, the CC view of CEDM was superior or comparable to that of MRI, and thus may be considered as the first choice for image reviewing and surgical planning.

The present study has a few limitations. First, the sample size was small. This was a prospective study in breast cancer patients before surgical management, which was conducted in a relatively short period. In the future, prospective multicentre studies with larger sample sizes should be conducted. Second, there was no uniformity in scheduling the time of surgery

Table 2. Concordance and linear regression of size using MG, CEDM, and CEMRI with its agreement of maximum tumour size including both invasive and *in situ* components

	MG			CEDM			CEMRI			
	MLO	CC	Max _{mg}	MLO	CC	Max _{cedm}	Sagittal MIP	Axial MIP	Max _{mip}	DCE _{1min}
Concordance										
Underestimation (%)	14 (35.0)	14 (38.9)	15 (35.7)	14 (29.2)	14 (30.4)	14 (28.0)	13 (25.5)	17 (34.0)	14 (28.0)	14 (27.5)
Concordance (%)	17 (42.5)	16 (44.4)	17 (40.5)	25 (52.1)	26 (56.5)	27 (54.0)	29 (56.9)	29 (58.0)	27 (54.0)	32 (62.8)
Overestimation (%)	9 (22.5)	6 (16.7)	10 (23.8)	9 (18.8)	6 (13.0)	9 (18.0)	8 (17.7)	4 (8.0)	9 (18.0)	5 (9.8)
Total	40	36	42	48	46	50	51	50	50	51
ICC (95% CI)	0.733 (0.495– 0.859)	0.750 (0.509– 0.872)	0.733 (0.503– 0.857)	0.827 (0.691– 0.903)	0.863 (0.752– 0.924)	0.856 (0.747– 0.918)	0.859 (0.758– 0.920)	0.884 (0.791– 0.936)	0.847 (0.733– 0.913)	0.813 (0.673– 0.893)
Linear regression analysis										
β (95% CI)	0.770 (0.430– 1.110)	0.730 (0.399– 1.062)	0.730 (0.412– 1.048)	1.038 (0.762– 1.315)	1.056 (0.831– 1.281)	0.976 (0.741– 1.211)	0.994 (0.720– 1.268)	1.117 (0.871– 1.363)	1.019 (0.773– 1.265)	1.015 (0.781– 1.249)
<i>p</i> value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
R ²	0.356	0.371	0.350	0.554	0.670	0.593	0.520	0.635	0.586	0.608

CC, craniocaudal; CEDM, contrast-enhanced digital mammography; CEMRI, contrast enhanced MRI; CI, confidence interval; DCE_{1min}, dynamic CEMRI at 1 min after contrast injection; ICC, intraclass correlation coefficients; MG, conventional mammography; MIP, maximal intensity projection; MLO, mediolateral oblique.

Figure 4. Bland-Altman plots for (a) MLO, (b) CC view, (c) maximum size of MG; (d) MLO, (e) CC view, (f) MAX of CEDM; (g) sagittal, (h) axial, (i) MAX of MIP, and (j) fat-suppressed axial T_1W DCE_{1min} between the maximum diameter including both invasive cancer and carcinoma *in situ* (OP_{max}) on pathology. CC, craniocaudal; CEDM, contrast-enhanced digital mammography; CEMRI, contrast-enhanced MRI; DCE_{1min}, dynamic CEMRI at 1 min after contrast injection; MAX, maximum size; MG, conventional mammography; MIP, maximal intensity projection; MLO, mediolateral oblique.

between the CEDM and CEMRI. The time interval between CEMRI and surgery was within 29 days, much longer than that between CEDM and surgery (within 8 days). Furthermore, there were 10 patients with a more than 9 day interval between MRI and surgery; thus, we decided to perform CEDM prior to the scheduled surgical date. Lastly, retrospective reports were used to correlate the CEDM, MRI, and histopathology observations, and one pathologist helped in evaluating the correlations for these parameters when some of the methods were unavailable.

CONCLUSION

All views of the CEDM and breast CEMRI were found to accurately measure tumour size. Overestimation was more frequent in the sagittal plane, and the method that was more accurate was the axial plane of CEDM and CEMRI. Therefore, CEDM can be used as an alternative modality to CEMRI in tumour size measurement, and the axial plane of the CEDM and CEMRI would be the first choice for image review and surgical planning. Furthermore, the highest accuracy is obtained by using the CC view of CEDM.

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