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FULL PAPER

Digital breast volume estimation (DBVE)—A new technique

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Objective: There are several limitations with current methods of breast volume measurement; principally relating to assumption of fixed shape forms. This study, utilizing computer aided volume estimates, developed a new method using the digital mapping of breast area and compares results to existing techniques of breast volume measurement and actual breast volume.

Methods: 50 consecutive breast cancer patients had breast volume calculated from mammograms [craniocaudal (CC) and mediolateral oblique views]; using breast height, width, radius, area and compression thickness. Area was recorded using cursor measurement tool for AGFA® Impax™6 software. The new volumetric estimation is based on the basic formula for the volume of a solid. The technique was compared with three known breast volume estimation techniques. Subsequently, 15 patients undergoing mastectomy had pre-op breast volume calculated using this new method and 3 existing

techniques; values were compared to fresh mastectomy weights/volumes.

Results: 50 patients, mean age 63.2 ± 14.4 (range 38–88) had breast volume estimation. The CC view appears to provide the best correlation with existing techniques. Scatterplots show a significant correlation of all the methods with the digital breast volume estimation method. Mastectomy volume compared with four breast volume techniques in $n = 15$, confined to the CC, shows good correlation between the digital technique and real volume. Scatterplots show significant correlation between digital breast volume estimation and mastectomy weight.

Conclusion: This study provided a novel simple tool to estimate breast volume in patients.

Advances in knowledge: This may aid in planning cosmetic outcome and oncoplastic approaches in breast cancer and breast reduction surgery.

INTRODUCTION

There have been several paradigm shifts in breast cancer care over the decades; from radical to conservative surgery; axillary clearance to selective sentinel node surgery and introduction of neo-adjuvant and targeted molecular therapy.^{1–4} Whatever advances have occurred, achieving acceptable cosmetic outcomes remains a major goal.^{5,6} This requires thorough pre-operative planning to include breast shape, symmetry and volume estimation.⁷ Obtaining a margin clear of tumour and with the smallest necessary volume excision is extremely important.^{5,8} Avoiding complications and re-excision is key to patient outcomes.⁹ Understanding the balance between tumour volume and breast volume is essential to ensure feasibility of successful breast conservation, especially in medial tumours and patients with smaller breast size. Poorer outcomes occur, in general, when more than 20% of breast volume is removed.¹⁰ The ratio of normal breast

tissue volume to tumour volume removed must be kept to a minimum.⁸ An accurate initial assessment of breast volume should be an invaluable tool to guide the surgeon. While several methods for measuring breast volume exist, there are a number of limitations with these methods; principally relating to assumption of fixed shape forms, such as cone or semi-ellipse, rather than actual volume.¹¹ All digital mammograms should facilitate volumetric analysis.

The aim of this study was, firstly, to develop a new method to calculate breast volume utilizing digital mammographic measurements and secondly, compare it to existing techniques of breast volume.

METHODS AND MATERIALS

A new digital breast volume estimation (DBVE)¹² technique was developed and compared with three existing breast volume measurement techniques. An ethically

Table 1. Formulae used for breast calculation methods 1–4

Method of calculation	Formula
Digital (DBVE) (Method 1)	(Digital mapping of area of breast tissue) × (compression thickness)
Kalbhen <i>et al</i> (Method 2)	$\frac{\pi}{4} \times (\text{Height}) \times (\text{width}) \times (\text{compression thickness})$
Katariya <i>et al</i> (Method 3)	$\frac{\pi}{3} \times (\text{radius CC})^2 \times (\text{hHeight CC})$
Fung <i>et al</i> (Method 4)	$\frac{\pi}{3} \times (\text{radius CC}) \times (\text{radius MLO}) \times (\text{height CC})$

CC, cranio caudal; DBVE, digital breast volume estimation; MLO, medio lateral oblique.

approved retrospective study was undertaken in 50 consecutive breast cancer patients to evaluate the new method. The hospital is a designated provider of breast cancer service.¹³ There are currently a number of reported methods of breast volume estimation and these are shown in Table 1. All patients have a routine two view mammogram with craniocaudal (CC) and mediolateral oblique (MLO) views.

For this study, breast volume was calculated using both the CC and MLO views. The CC view was calculated using breast height (defined as the longest perpendicular distance from the pectoralis major to the back of the nipple), breast width (BW) (the distance from the most lateral point of breast tissue to the most medial point of breast tissue (measured skin to skin), radius (recorded as half the BW), area (area of breast tissue seen on the mammogram) and compression thickness. Compression thickness was defined as the distance in millimetres between the upper moveable plate and the lower, fixed, X-ray plate on the GE Seno Essential mammography machine and recorded by the digital system AGFA IMPAX 6 software™ [™AGFA (Am Coloneum 4, 50829 Köln, Germany) IMPAX 6 software] The mammography machine exerts a maximum pressure of up to 15 daN. The breast acts as a single sphere with loss in height replaced by increased transverse diameter.¹⁴

Breast volume on the MLO view was calculated using similar definitions as used for CC view calculations except BW was defined as the distance from the most inferior point of breast tissue to the most superior point of breast tissue including that beyond the thoracodorsal artery. Volumes were calculated using both CC and MLO views. Figures 1 and 2 show visual images of how both CC and MLO measurements are calculated using methods 2, 3 and 4.

Volume calculations

For comparison, four methods of volume calculation were undertaken; the new DBV and three existing ones. All four formulae are shown in Table 1.

Method 1: the new digital volumetric estimation uses the computer's cursor to manually map the area of breast tissue viewed on the mammogram (both CC and MLO). Once the complete two-dimensional shape has been traced around the margin of tissue, the software calculates the area of the shape traced (*i.e.*

Figure 1. CC image with measurements needed to calculate methods 2, 3 and 4 (compression thickness value is not shown). Breast height = X–Y; breast width = A–B. CC, cranio caudal.

breast area). This value of two-dimensional area is then multiplied by compression thickness to calculate three-dimensional breast volume. Both CC and MLO projections were individually used to measure volume. An example of how breast area is digitally displayed on the AGFA IMPAX 6 software is displayed in Figure 3. The compression thickness is automatically calculated and displayed in the service window of the software under code 0018 11a0—body part thickness and is measured in mm.

Method 2: Kalbhen's method from 1999¹⁵ defines the shape of the breast as a half elliptical cylinder; the thickness of the cylinder is represented by recorded compression thickness. Breast height and width measurements are also required.

Method 3: Katariya's technique from 1974¹⁶ is based on the algebraic formula for the volume of a circular base cone. It measures volume from the CC projection. Breast height and radius measurements are taken from the CC projection.

Method 4: Fung's breast volume calculation from 2010¹⁷ bases the shape of the breast on an elliptical cone, volume is calculated using breast height and radius measurements from CC projection as well as a radius measurement from MLO view. Both Katariya's and Fung's methods are unsuitable for measuring breast volume specifically in MLO views.^{16,17}

In the second part of the study, 15 prospectively studied patients undergoing mastectomy had their pre-op breast volume

Figure 2. MLO image measurements needed to calculate methods 2, 3 and 4 (compression thickness value is not shown). Breast height = X–Y; breast width = C–DG. MLO, medio lateral oblique.

calculated using this new method and the 3 existing techniques and these values were then compared to their actual fresh mastectomy weights/volumes.

If the patient underwent wide local excision before mastectomy, then the weight of this excision was added to the mastectomy weight so that comparison with the methods was more accurate. The mastectomy weight was then converted to a volume using the principle that 1 g of breast tissue equals 1 cm³ of tissue.¹⁸

Data were expressed as mean and standard deviation for normally distributed data and medians and interquartile range for non-normal data. Comparison of measurements from DBVE and the other methods was analysed using scatter plots and the strength of linear relationships measured using Pearson's correlation coefficient.

RESULTS

50 patients, mean age 63.2 ± 14.4 (range 38–88) had breast volume estimation. The comparison of volumes of breast tissue measured in CC view ($n = 50$) using the new proposed digital method and three existing methods is shown in Table 2. The CC view appears to provide the best correlation with existing

Figure 3. Measurements needed for new DBVE method calculations. Cc and MLO images with breast area (mrrr) automatically calculated and displayed on screen by AGFA (Am Coloneum 4,50829 Kain, Germany) IMPAX 6 software™ (Compression thickness value is not shown). CC, cranio caudal; DBVE, digital breast volume estimation; MLO, medio lateral oblique.

techniques. Breast volume (cm³) from the right MLO view was 964 ± 561 (176–2695) using the digital method and 1036 ± 549 (210–2596) using Kalbhen's method. In the left MLO view, breast volume was 970 ± 543 (179–3044) using the digital method and 1032 ± 517 (204–2919) using Kalbhen's method. Further analysis was undertaken in the form of scatter plots. Comparison of Katariya et al vs DBVE (Figure 4a,b) yielded a correlation coefficient (r) value of $r = 0.91$ in the RCC view and $r = 0.92$ in the LCC view. Comparison of Fung et al with DBVE (Figure 5a,b) correlation coefficient values $r = 0.93$ were found in the RCC view and $r = 0.90$ in the LCC view. On comparison with Kalbhen et al and DBVE, (Figure 6a–d) the correlation coefficient was $r = 0.99$ in the RCC view, $r = 0.99$ in the LCC view, $r = 0.98$ in the RMLO view and $r = 0.97$ in the LMLO view. This shows a significant correlation of all the methods with the DBVE method.

The comparison of mastectomy volume with the four breast volume techniques in $n = 15$ is shown in Table 3. This analysis, confined to the CC, shows good correlation between the technique and real volume.

Mastectomy weights and DBVE were also compared using scatter plots (Figure 7a,b) correlation coefficients of $r = 0.91$ in the CC view and $r = 0.94$ in the MLO view were found. This showed a significant correlation between DBVE and mastectomy weight.

DISCUSSION

This study has developed a novel, simple, digital method of BVE. Understanding breast volume and creating absolute values is helpful in facilitating the planning and execution of surgical breast interventions. The need for improved methods of breast

Table 2. Comparison of digital and existing breast volume methods using CC view ($n = 50$)

Projection		1 Digital (cm ³)	2 Kalbhen (cm ³)	3 Katariya (cm ³)	4 Fung (cm ³)
CC (right)	Mean($\pm$ SD)	778 ($\pm$ 471)	782 ($\pm$ 457)	932 ($\pm$ 543)	964 ($\pm$ 499)
	Range	145–2042	155–2000	250–2890	330–2643
CC (left)	Mean($\pm$ SD)	760 ($\pm$ 449)	765 ($\pm$ 436)	936 ($\pm$ 546)	956 ($\pm$ 485)
	Range	145–2466	151–2375	283–3073	389–2842

CC, cranio caudal; SD, standard deviation.

volume determination is made apparent by the long list of publications on the topic. Current methods of volume calculation exhibit variable reliability; many require a level of detail that is difficult to reproduce, are impractical, are often not cost effective or may not be acceptable to the patient.¹⁹ The need for benchmarks and standards in cosmetic outcome assessment following breast cancer surgery have been recently emphasised.^{20,21} In addition with volume assessment, we should not forget the potential effects of adjuvant therapies on outcome.²² The principle of the DBVE technique is that the picture of the breast, on a mammogram, of any shape can now have its volume estimated. This requires a simple measurement of breast area on mammogram

multiplied by the breast thickness (compression thickness). This has potential advantage over other formulae as it can measure a variety of breast shapes accurately without having to conform to any fixed form of shape, *e.g.* cones and cylinders.

It has been noted that there is a potential for error in formulae which are only accurately reproducible on CC mammograms. In females with larger breasts, the base of the breast can sometimes be missed which can lead to inaccuracies in volume measurement.¹⁷ Our DBVE can measure volumes from the MLO view. The validity of this DBVE in patients with previous breast conserving surgery was not assessed in this study, but depending

Figure 4. Scatter plot analysis of Katariya *et al* vs. DBVE. LCC, left cranio caudal; DBVE, digital breast volume estimation; RCC, right cranio caudal.

a

b

Figure 5. Scatter plot analysis of Fung vs. DBVE. LCC, left cranio caudal; DBVE, digital breast volume estimation; RCC, right cranio caudal.

a

b

Figure 6. Scatterplot analysis of Kalbhen et al vs DBVE.

Figure 6 – Scatter plot analysis of Kalbhen et al vs DBVE

on the previous volume loss and deformity could be a source of error. A potential advantage in this subgroup, however, would be symmetry analysis following previous surgery or prior to mastectomy using contralateral breast volume to devise a quantitative estimate of asymmetry.

DBVE measurements were similar to those obtained using the Kalbhen et al¹⁵ method, which has the most linear relationship with mastectomy specimen volumes when compared to other methods such as that of Katariya et al.¹⁶

Asymmetry in size following breast conserving surgery is one of the most important factors contributing to aesthetic results.²³ A potential application of our new method is in measuring breast volume after breast conserving surgery. The method could be

used to more accurately measure irregular breast volumes so that post-operative breast volume figures could be obtained making any future surgeries better informed.

A potential for error in our method is that it assumes breast curvature is constant, which is not the case in reality. The margin of error in this case could only be assessed against a gold-standard, which has not been done in this study but is an area for further testing of the method. Patients who have had previous breast surgery, either benign or malignant, with potential post-operative deformity could pose a confounder to accurate breast volume estimation. This would also apply to radiotherapy.

The comparison of our method to largely outdated methods of breast volume measurement such as Katariya et al, Fung et al and

Table 3. Comparison of mastectomy volumes with different breast volume measurement techniques using CC view: $n = 15$

Projection	Method	Real Volume (cm ³)	Digital (cm ³)	Kalbhen (cm ³)	Katariya (cm ³)	Fung (cm ³)
CC	Mean($\pm$ SD)	777 ($\pm$ 669)	691 ($\pm$ 538)	715 ($\pm$ 526)	726 ($\pm$ 512)	762 ($\pm$ 453)
	Range	195–2526	176–2455	192–2438	208–2202	249–2051

CC, cranio caudal; SD, standard deviation.

Figure 7. Scatter Plot analysis of Mastectomy weight vs DBVE.

Kalbhen et al could be criticised. Volpara mapping²⁴ and MRI scanning¹⁹ have been validated versus mastectomy volumes and have been shown to accurately assess breast volume and breast density suggesting that their use may be more relevant.

When comparing our method to mastectomy weights, minor inaccuracies may have arisen in assuming that the density of breast tissue in a specimen was 1 g/cm^3 . As with other breast volume studies previously published, our analysis was performed with the assumption that, as far as the breast is concerned, volume would be at a 1:1 ratio with the weight (1 g/cm^3).^{18,25} Calculating actual breast weight from volume is problematic due to the significant range in fibroglandular to adipose ratios (reflected by percent density) demonstrated in breast anatomy.²⁶ Volpara software calculates the total breast volume and fibroglandular breast volume which then allows for adipose tissue volume to be derived. Using Volpara to convert each tissue type volume to a

weight (e.g. 1 g/cm^3 for fibroglandular vs 0.9 g/cm^3 for adipose) may improve the correlation to mastectomy weights. However, MRI breast scanning and Volpara mapping is not available in every hospital so, in their absence, DBVE may be considered to achieve the same outcome. Combining breast volume with density analysis may have dual benefit both in cosmesis and cancer risk assessment. The patients in this study underwent mammography essential for diagnostic work-up of cancer care unlike patients under 30 for whom DBVE would be unsuitable due to radiation exposure.

Mastectomy weights in our study were measured in the operating room before fixation, as fixative solution can influence breast specimen weights particularly in larger breasts.²⁷ Another limitation of our method is that, currently, DBVE is not an automatic method of estimating the breast volume. This is a possible consideration after a validation study of the method against mastectomy volume or MRI volume.

Our study was limited in that interobserver variability was not measured. In addition, the sample size of mastectomies used was small ($n = 50$). Measurements were only taken once, as opposed to other studies determining volume from mammography where measurements were taken several times.¹⁹ We did not take into account changes in volume depending on stage of menstruation and its potential to effect on breast volume.²⁸ Additionally, attenuation near the skin edge is not considered in our method.

Another limitation of our study is that we do not compare our results to a gold-standard. In order for our method to be verified, we will need further comparison of our method to mastectomy patients who have had their breast volume measured using water displacement techniques.¹⁸ This is considered the gold standard in breast volume measurement as it is the only way to define the volume of the breast without missing or adding volume.²⁹

This study is an addition to existing breast volume estimation techniques in the digital era. It may help focus the mind of the surgeon on the patient's breast volume and help obtain an appropriate cancer clearance while maintaining cosmesis. At a time where there is increasing scrutiny of margin positivity rates, reducing without compromising breast volume excision is becoming more important. Objective measures of breast volume will help focus surgical decision making in surgery to improve outcome.⁸

In conclusion, this study provides a novel, simple tool to estimate breast volume in patients. It has the potential to aid in planning cosmetic outcome and oncoplastic approaches in breast cancer and breast reduction surgery.

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