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# Prediction of Implant Size Based on Breast Volume Using Mammography with Fully Automated Measurements and Breast MRI

**Young Seon Kim, MD[1], Hyun Geun Cho, MD[2], Jaeil Kim, PhD[3], Sung Joon Park, MS[3], Hye Jung Kim, MD, PhD[4], Seung Eun Lee, MD[1], Jung Dug Yang, MD, PhD[2], Won Hwa Kim, MD, PhD[4], and Joon Seok Lee, MD, PhD[2]**

[1]Department of Radiology, Yeungnam University Hospital, Yeungnam University College of Medicine, Daegu, Republic of Korea; [2]Department of Plastic and Reconstructive Surgery, School of Medicine, Kyungpook National University, Daegu, Republic of Korea; [3]School of Computer Science and Engineering, Kyungpook National University, Daegu, Republic of Korea; [4]Department of Radiology, School of Medicine, Kyungpook National University, Kyungpook National University Chilgok Hospital, Daegu, Republic of Korea

## ABSTRACT

**Background.** Determination of implant size is crucial for patients with breast cancer undergoing one-stage breast reconstruction. The purpose of this study is to predict the implant size based on the breast volume measured by mammography (MG) with a fully automated method, and by breast magnetic resonance imaging (MRI) with a semi-automated method, in breast cancer patients with direct-to-implant reconstruction.

**Patients and Methods.** This retrospective study included 84 patients with breast cancer who underwent direct-to-implant reconstruction after nipple-sparing or skin-sparing mastectomy and preoperative MG and MRI between April 2015 and April 2019. Breast volume was measured using (a) MG with a fully automated commercial software and (b) MRI with an in-house semi-automated software program. Multivariable regression analyses including breast volume and patient weight ($P < 0.05$ in univariable analysis) were conducted to predict implant size.

**Results.** MG and MRI breast volume was highly correlated with both implant size (correlation coefficient 0.862 and 0.867, respectively; $P$ values $< 0.001$) and specimen weight (correlation coefficient 0.802 and 0.852, respectively; $P$ values $< 0.001$). Mean absolute difference between the MR breast volume and implant size was 160 cc, which was significantly higher than that between the MG breast volume and implant size of 118 cc ($P < 0.001$). On multivariable analyses, only breast volume measured by both MG and MRI was significantly associated with implant size in any implant type (all $P$ values $< 0.001$).

**Conclusion.** Breast volume measured by MG and MRI can be used to predict appropriate implant size in breast cancer patients undergoing direct-to-implant reconstruction in an efficient and objective manner.

Won Hwa Kim and Joon Seok Lee have contributed equally to this work.



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W. H. Kim, MD, PhD
e-mail: greenoaktree9@gmail.com

J. S. Lee, MD, PhD
e-mail: leejspo@knu.ac.kr

According to the World Health Organization, breast cancer is the most common cancer globally and more patients are considering reconstructive breast surgery after curative resection to improve their quality of life.[1, 2] Especially for patients who undergo mastectomy, nipple- or skin-sparing mastectomy has been more employed with various approaches on the basis of the breast's size and shape for better cosmetic results.[3] In addition, implant-based reconstruction technique is one of the most popular methods to restore the breast's shape.

This technique has been based on two strategies:[4–6] (a) a two-stage approach with tissue expansion and (b) a single-stage (direct-to-implant) approach. Assessment of breast volume is helpful to determine the size of implants during direct-to-implant breast reconstruction.[4]

Conventionally, the size of implant is determined by visual inspection or by use of a temporary sizer during surgery; however, these methods are subjective and highly dependent on the surgeon's experience. More objective methods, including Archimedean principle, thermoplastic casting, anthropomorphic measurement, and imaging, have been reported.[7–12] Breast magnetic resonance imaging (MRI), allows us to estimate the breast volume given its three-dimensional coverage of the entire breast volume as an imaging modality used in the preoperative assessment of the tumor's spatial extent. Several reports have been published on its potential applications.[11, 13–16] In previous reports, the estimated breast volume using MRI was closely correlated with the final flap weight for autologous breast reconstruction, the implanted volume for implant-based reconstruction, and mastectomy specimen weight.[15, 16] Among the several published methods for breast volume measurement, MRI yielded the highest accuracy and reproducibility.[11, 13, 14] Nonetheless, breast volume measurements with MRI have not been clinically used for the following reasons. First, breast MRI is not a commonly used imaging modality owing to its limited clinical efficacy, high cost, and the use of contrast agents. Second, the measurement of breast volume using MRI requires specialized software. Even in the cases wherein the software is available, the measurement of breast volume is labor intensive and time consuming because manual verification of the breast surfaces and chest wall is still needed. Conversely, mammography (MG) is a routine imaging modality for breast surgery that enables us to assess the entire breast volume with two different views (craniocaudal and mediolateral oblique). The currently available commercial software Volpara (version 1.5.1, Volpara Health Technology, Wellington, New Zealand) measures breast volumes using MG in conjunction with a fully automated method.[5] The software was originally developed for estimating and reporting on the breast density (fibroglandular tissue volume divided by breast volume). To our knowledge, there have are no reports to date on the use of this fully automated estimation of breast volume for the prediction of implant size. If the breast volume could be measured by this software, the implant size could be determined with this method in a more time-efficient and objective manner compared with MRI or visual inspection. Thus, the aim of our study is to predict implant size on the basis of breast volume measured by MG with a fully automated method,[17] and to conduct breast MRI with a semi-automated method, in patients with breast cancer who underwent direct-to-implant reconstruction.

## PATIENTS AND METHODS

### *Patients and Image Acquisition*

This retrospective study was approved by the institutional review board (for the review of medical records), and the requirement for informed consent was waived. Between April 2015 and April 2019, we identified 87 consecutive women who underwent direct-to-implant breast reconstruction after nipple- or skin-sparing mastectomy for therapeutic purpose and MG and breast MRI before surgery. Among these patients, three patients with existing breast implants were excluded and no patients had bilateral diseases. Finally, 84 women (mean age, 46.6 $\pm$ 7.2 years; range, 28–66 years) were included in this study. Clinical information was collected for age, height, weight, and operation side. Surgical information was collected for implant location, implant type, implant size (cc), and specimen weight (g) (Table 1). All mammographic examinations were performed with the use of one full field digital MG unit (Lorad Selenia, Hologic, Bedford, MA) with standard craniocaudal and mediolateral oblique views for each breast. Breast MRI was routinely performed in our clinic for the initial staging of breast cancer in a prone position using a 3.0-T system (Discovery MR750, General Electric Healthcare, Waukesha, WI) with a dedicated eight-channel surface breast coil. Axial T1-weighted images [repetition time (ms)/echo time (ms), 746/10; matrix, 352 $\times$ 256; slice thickness, 3 mm] and axial fat-suppressed T2-weighted images (8087/88; 384 $\times$ 256; 3 mm) were acquired. Dynamic contrast material–enhanced bilateral axial MRI included one precontrast and five postcontrast phases using three-dimensional gradient echo, fat-suppressed, T1-weighted imaging (4/2; 288 $\times$ 416; 1 mm; flip angle, 15°).

### *Direct-to-Implant (DTI) Breast Reconstruction*

Our clinical protocol for the assessment of breast volume is to use a thermoplastic casting method in which a cast of the breast is made using clinical tapes (3M soft cloth tape with liner) onto the breasts. This breast cast maintains its shape and is filled with water. The breast volume is determined by the amount of water filled in the cast. The subcutaneous flap dissection was then performed by removing breast parenchyma from the inframammary line (inferior boundary of the breast), the midaxillary line (lateral boundary), the clavicle (superior boundary), and

**TABLE 1** Patient characteristics

| Characteristic | Value |
|---|---|
| Age, years* | 46.6 ± 7.2, 46 (28–66) |
| Height, cm* | 158.9 ± 5.7, 158.6 (146.8–171.8) |
| Weight, kg* | 54.7 ± 6.5, 53 (43.3–78.5) |
| BMI, kg/m$^2$* | 21.7 ± 2.2, 21.49 (17.4–30.0) |
| *T stage* | |
| 0 | 25 (29.8) |
| 1 | 51 (60.7) |
| 2 | 8 (9.5) |
| *N stage* | |
| 0 | 65 (77.4) |
| 1 | 19 (22.6) |
| *Mastectomy type* | |
| SSM | 26 (31.0) |
| NSM | 58 (69.0) |
| *Operation side* | |
| Left | 38 (45.2) |
| Right | 46 (54.8) |
| *Implant location* | |
| Subpectoral | 51 (60.7) |
| Prepectoral | 33 (39.3) |
| *Implant type* | |
| Allergan | 42 (50.0) |
| Bellagel | 8 (9.5) |
| Mentor | 34 (40.5) |
| MG breast volume, cm$^3$* | 359.3 ± 199.2, 322.6 (74.1–1157.1) |
| MRI breast volume, cm$^3$* | 407.8 ± 211.1, 366.1 (74.2–1272.8) |
| Specimen weight, g* | 295.1 ± 132.6, 270.5 (50.0–709.0) |
| Implant volume, cc* | 251.9 ± 88.6, 240 (90–470) |

*SSM* skin-sparing mastectomy, *NSM* nipple-sparing mastectomy, *MG* mammography, *MRI* magnetic resonance imaging

Unless otherwise specified, data are presented as number of patients, with percentage in parentheses

*Data presented as mean ± SD and median (range)

the sternum (medial boundary). Subcutaneous undermining was performed through the surgical incision along the entire surface of the breast followed by retro glandular undermining to complete subcutaneous mastectomy. Immediately after the mastectomy was completed, the most appropriate implant size was selected intraoperatively by the breast plastic surgeon, using an implant sizer to ensure breast symmetry, on the basis of references of the measured breast volume.

### Breast Volume Measurements

As breast cancers may affect the morphological shape of the diseased breast, breast volume was determined using the contralateral (nondiseased) breast as previous studies and assumptions indicate that women generally have symmetric breasts and reconstruction surgery is aimed to equalize bilateral breast volume.[9, 18] MG-based breast volume was measured using the fully automated, commercial software Volpara (version 1.5.1, Volpara Health Technology, Wellington, New Zealand) (Fig. 1). This software automatically displays breast volume (cm$^3$), fibroglandular tissue volume (cm$^3$), and breast density (%) per breast (average values of craniocaudal and mediolateral oblique views) on the picture archiving and communication system. Volpara's algorithm has been described in previous reports.[19–21] It uses relative physics modeling using a reference level as a calibration object. The calibration object corresponds to adipose tissue (usually retromammary fat near the chest wall) to determine the thickness of dense fibroglandular tissue at each pixel estimated by the X-ray attenuation in that pixel. The volume of fibroglandular tissue is determined by the integration of the thickness of dense tissue over the image. Breast volume is determined by multiplying the area of the breast by the recorded breast thickness. Breast density is the percentage ratio of the fibroglandular tissue volume and breast volume.

MRI breast volume was measured using an in-house software (Fig. 2) based on the Medical Imaging Interaction Toolkit (MITK, Version 2018.04).[22] The MRI breast volume measurement was achieved by a semi-automated breast region segmentation. In this process, we used the Segmentation plugin with three-dimensional (3D) contour interpolation in the MITK Workbench.[23] The 3D contour interpolation provides the boundaries of breast in unsegmented MRI slices between manually segmented slices. We delineated breast regions from the first, middle, and last axial slices wherein the breast was observed. Then, we reviewed the breast contours, which were provided by the interpolation function, and verified the segmented breast tissue. For images that were not correctly segmented, manual segmentation was applied.

### Statistical Analysis

Mean differences were calculated as mean values of relative difference obtained by subtracting implant size from the breast volume at MG or MRI measurements. Mean values between the implant size and MG or MRI breast volume estimates were compared using paired *t* tests. Comparison between mean values of MG breast volume and MRI breast volume was also analyzed. Mean differences were calculated and compared using independent *t* tests or one-way of variance according to clinical variables of age, height, weight, mastectomy type (skin versus nipple sparing), implant location (subpectoral versus prepectoral), and implant type (Allergan, Bellagel,

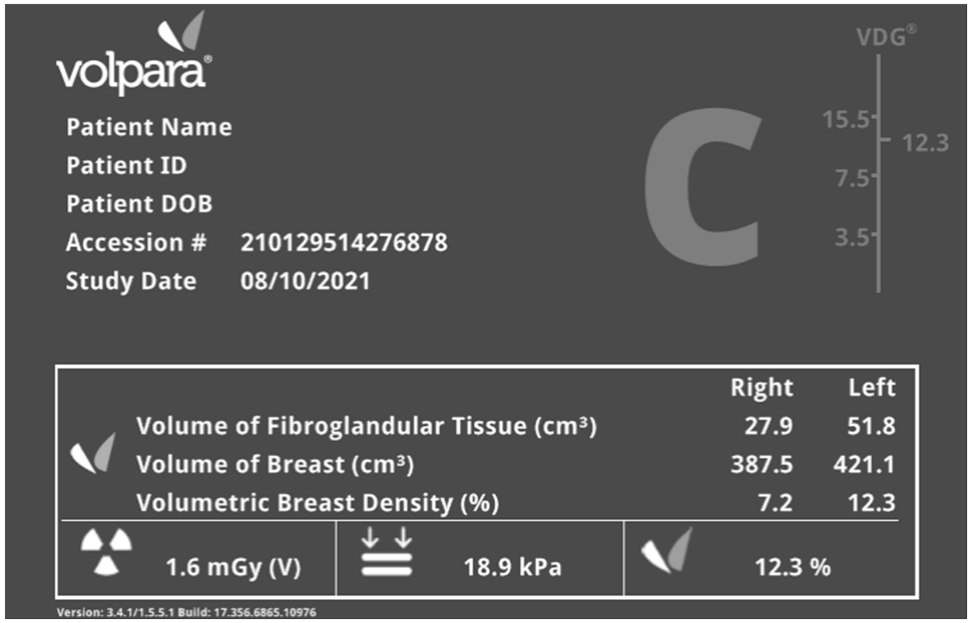


**FIG. 1** Screenshot of volumetric measurement of mammography using the Volpara software. It automatically displays breast volume ($cm^3$), fibroglandular tissue volume ($cm^3$), and breast density (%) per breast (averaged values of craniocaudal and mediolateral oblique views) on the picture archiving and communication system

Mentor); continuous variables were divided into binary groups using the median value.

The Pearson's correlation coefficient was used where the implant size and breast volume (measured by MG or MRI) were associated. Correlation coefficients indicate a strong, moderate, weak, and almost nonexistent correlation for values $\geq$ 0.8, 0.5–0.8, 0.3–0.5, and < 0.3, respectively. Univariable linear regression analysis was performed to describe the relationship between implant size and each variable, including MG and MRI breast volume. Multivariable regression analyses including breast volume and patient weight ($P < 0.05$ in univariable analysis) were conducted to predict implant size in groups with implant types (Allergan or Bellagel versus Mentor). The coefficient of determination ($R^2$) was calculated as the proportion of the variation in the implant size explained by the regression model (goodness of fit). Adjusted $R^2$ was also calculated as the coefficient of determination adjusted for the number of independent variables in the regression model. The Bland–Altman plot was used for analysis of correlations between MG breast volume versus implant size and between MRI breast volume and implant size (Fig. 3). All statistical analyses were performed with the statistical software SPSS (version 24.0, Chicago, IL) and MedCalc (version 17.1, Mariakerke, Belgium). The two-tailed test ($P < 0.05$) was considered indicative of a statistically significant difference.

## RESULTS

The patient characteristics and entire dataset are listed in Table 1. The mean patient age was 46.6 years [standard deviation (SD), 7.2 years; range, 28–66 years]. Of the 84 enrolled patients, nipple-sparing mastectomy was performed on 58 (69.0%) and skin-sparing mastectomy on 26 (31.0%) patients. The implant was replaced in subpectoral regions in 51 patients (60.7%) and in prepectoral regions in 33 patients (39.3%). Regarding the type of implant, Allergan was used in 42 patients (50.0 %), Bellagel in 8 (9.5%), and Mentor in 34 (40.5%).

The mean specimen weight was 295.1 g (SD, 132.6 g; range, 50–709 g), and the mean implant volume was 251.9 cc (SD, 88.6 cc; range, 90–470 cc). The mean MG breast volume was 359.3 $cm^3$ (SD, 199.2 $cm^3$; range, 74.1–1157.1 $cm^3$), and the mean MRI breast volume was 407.8 $cm^3$ (SD, 211.1 $cm^3$, range, 74.3–1272.9 $cm^3$). MRI breast volume was larger than MG breast volume ($P < 0.001$). The mean MG and MRI breast volume estimates were significantly higher than the implant size (mean differences, 107.3 and 155.9, respectively, all $P$ values < 0.001). Mean difference between breast volume and implant size was significantly higher in MR than MG ($P < 0.001$). Mean difference was also significantly different according to implant types in both MG and MRI measurements ($P$ = 0.027 and $P$ = 0.043, respectively). A higher mean difference between MG or MRI breast volume and implant size was found in the group with Mentor type in comparison with the other implant types (Table 2). Patients with higher body weights ($\geq$ 53.5 kg) had significantly higher mean differences between breast volume and implant size in both MG- and MRI-based measurements (all $P$ = 001).

In our study, specimen weight was highly correlated with implant size (correlation coefficient 0.847, $P < 0.001$). MGbreast volume was highly correlated with implant size (correlation coefficient 0.862, $P < 0.001$) or specimen

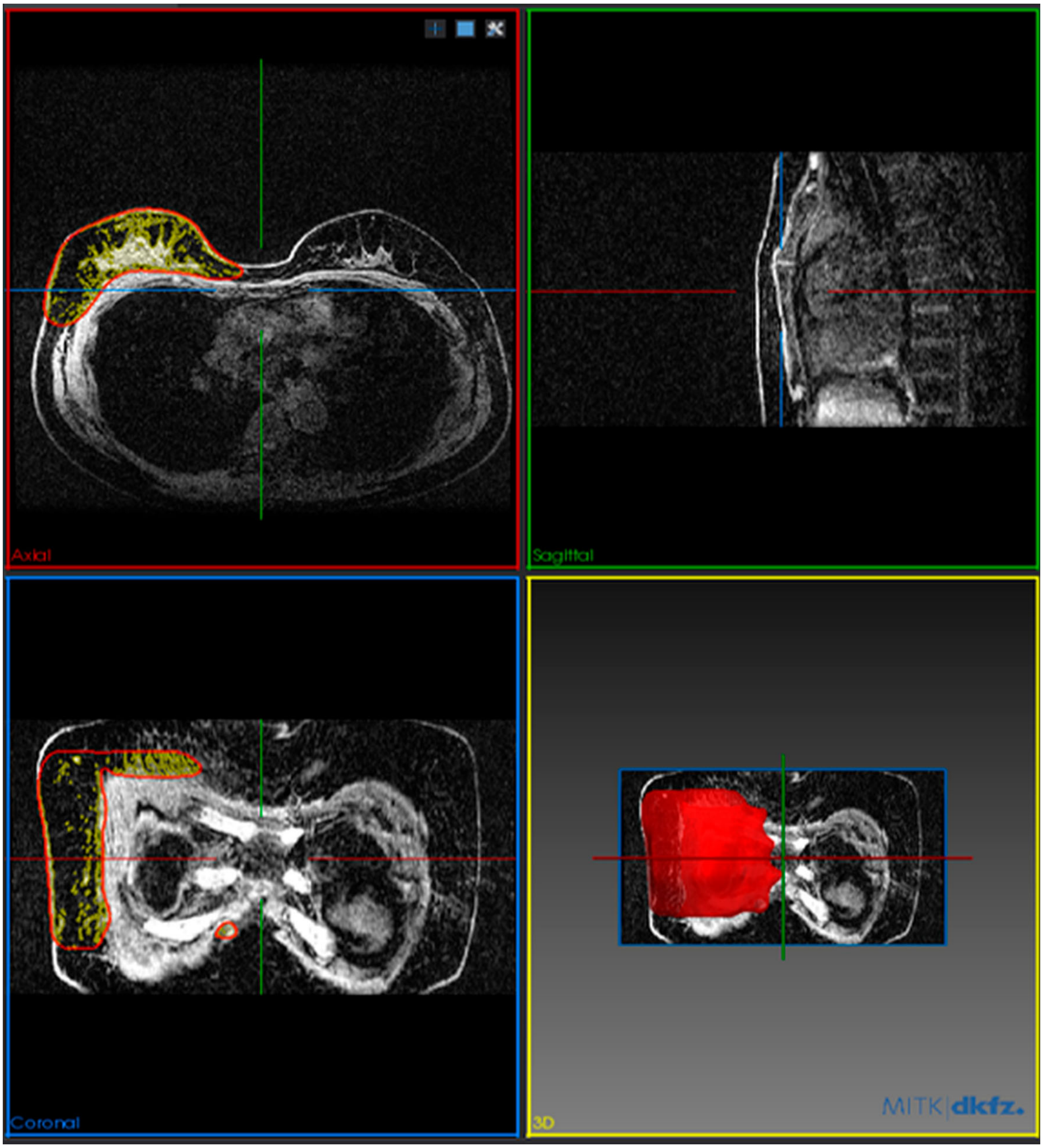


**FIG. 2** Breast volume measurement using magnetic resonance imaging (MRI) with in-house software. The three-dimensional contour interpolation provides the boundaries of breast in unsegmented MRI slices between manually segmented slices. We first delineated breast regions from the first, middle, and last axial slices wherein breast tissue was observed. Subsequently, we reviewed the breast contours, which were provided by the interpolation function, and verified the segmented breast tissue. For images that were not correctly segmented, manual segmentation was applied

weight (correlation coefficient 0.802, $P < 0.001$). MRI breast volume was highly correlated with the implant size (correlation coefficient 0.867, $P < 0.001$) or specimen weight (correlation coefficient 0.852, $P < 0.001$). On univariate linear regression analysis for the prediction of the implant size (Table 3), body weight, implant type, MG, and MRI breast volume, were significantly associated with implant size (all $P < 0.001$). We divided into two groups on the basis of implant type (Allergan or Bellagel versus Mentor), and multivariable linear regression was performed in each group. The results showed that MG- or MRI-based breast volume estimates were associated consistently with implant sizes (all $P < 0.001$). Based on these results, the implant size can be estimated by the following equation as follows with each $R^2$ and adjusted $R^2$ (Table 4):

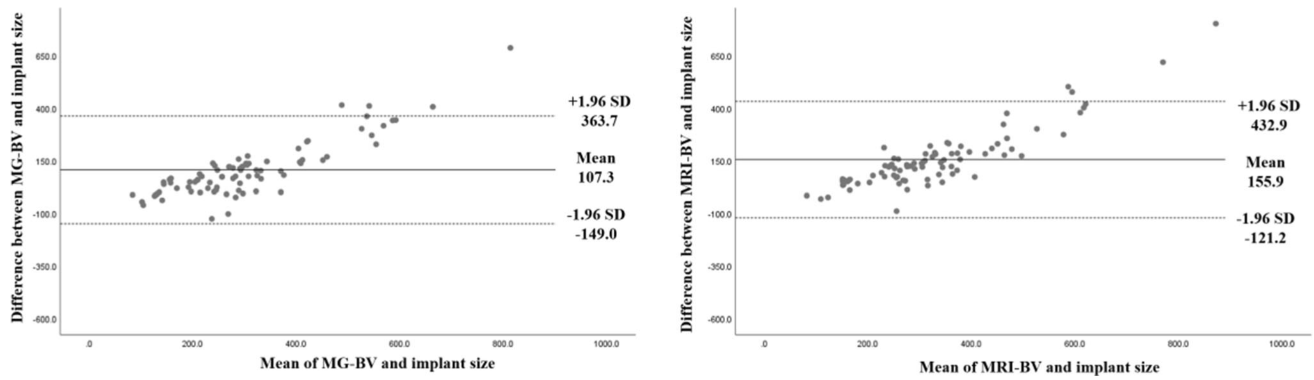


**FIG. 3** Bland–Altman plot used for analysis of correlation between MG-BV versus implant size and between MRI-BV versus implant size. *MG-BV* MG breast volume, *MRI-BV* MRI breast volume

For the Allergan or Bellagel types:

$$\text{Implant size} = 0.4 \times \text{ breast volume } \left(\text{MG, cm}^3\right) + 2.1 \times \text{ weight (kg)} + 6.5\left(R^2 = 74\%, R^2 - \text{adjusted} = 73\%\right)$$

$$\text{Implant size} = 0.3 \times \text{ breast volume } \left(\text{MRI, cm}^3\right) + 3.2 \times \text{ weight (kg)} - 64.5(R^2 = 77\%, R^2 - \text{adjusted} = 76\%)$$

For the Mentor types

$$\text{Implant size} = 0.3 \times \text{ breast volume } \left(\text{MG, cm}^3\right) + 1.6 \times \text{ weight (kg)} + 73.0\left(R^2 = 69\%, R^2 - \text{adjusted} = 67\%\right)$$

$$\text{Implant size} = 0.3 \times \text{ breast volume } \left(\text{MRI, cm}^3\right) + 0.4 \times \text{ weight (kg)} + 124.7\left(R^2 = 71\%, R^2 - \text{adjusted} = 69\%\right)$$

The actual range of implant size placed in this study and the specimen weight according to the MG breast volume and weight are listed in Table 5. Even though there is an individual variation, a stepwise positive correlation was observed between the MG breast volume and implant size.

## DISCUSSION

With earlier diagnosis and advanced treatment strategies, long-term survivors of breast cancer can live with the postoperative esthetic outcome for the rest of their life. Reconstructive breast surgery has thus evolved new approaches over the years, tailoring strategies according to patients' breast volume and shape. Thus, preoperative acknowledgement of the breast information is useful for individualized surgical planning. In the present study, we investigated the breast volume measured by MG with a fully automated method and by breast MRI with a semi-automated method to predict implant size in patients with breast cancer who underwent direct-to-implant reconstruction. Our study suggests that breast volume measurements based on MG with the fully automated method can potentially be used to predict implant size before breast reconstruction. We found that MG breast volume (correlation coefficient 0.862, $P < 0.001$) was highly correlated with implant size, as a high correlation was also found between MRI breast volume and implant size (correlation coefficient 0.867, $P < 0.001$). One of the strengths of our study is that we introduced an easy and more practical method using MG for breast volume measurements. We used a commercial, fully automated software that is extensively used in mammographic examinations. As this fully automated software requires no manual manipulation, volume measurement with MG could become a more efficient way in daily clinical practice, compared with the MRI-based method, which is more laborious and time consuming.

Breast volume determination is a crucial component in preoperative planning to achieve patient satisfaction in reconstruction procedures.[7] Given that breast shape is highly variable among patients and redundant according to the patient position, many techniques have been used to conduct objective analyses of breast volume. They have been categorized as follows: Archimedean principle, thermoplastic casting, anthropomorphic measurement, and imaging. Archimedean principle in conjunction with a water displacement technique has shown a great agreement with mastectomy specimen;[24, 25] however, it needs a specialized device, and lateral breast tissue is often missed. Thermoplastic casting is a method that uses plaster or thermoplastic sheets applied onto the chest wall, thus creating a mold from which volume can be measured with either sand or water.[7, 10] Despite its easy accessibility, it is subjective owing to arbitrary determinations made to define the breast boundaries by manually applying thermoplastic material. Anthropomorphic measurements are used to

**TABLE 2** Mean differences in breast volume and implant size

| Variable | MG breast volume, cm$^3$—implant volume, cc | *P*-value | MRI breast volume, cm$^3$—implant volume, cc | *P*-value | Specimen weight—implant volume, cc | *P*-value |
|---|---|---|---|---|---|---|
| Age, years | | 0.257 | | 0.138 | | 0.429 |
| < 47 (*n* = 44) | 91.8 ± 104.9 | | 134.0 ± 107.3 | | 36.7 ± 46.0 | |
| ≥ 47 (*n* = 40) | 124.4 ± 153.9 | | 179.9 ± 169.4 | | 50.1 ± 96.7 | |
| Height, cm | | 0.387 | | 0.471 | | 0.228 |
| < 159 (*n* = 43) | 95.2 ± 100.4 | | 144.9 ± 105.3 | | 33.5 ± 75.5 | |
| ≥ 159 (*n* = 41) | 120.1 ± 156.8 | | 167.4 ± 171.9 | | 53.2 ± 72.8 | |
| Weight, kg | | 0.001 | | 0.001 | | 0.207 |
| < 53.5 (*n* = 43) | 63.1 ± 74.0 | | 106.8 ± 87.4 | | 33.1 ± 74.3 | |
| ≥ 53.5 (*n* = 41) | 153.7 ± 159.5 | | 207.4 ± 167.7 | | 53.7 ± 74.0 | |
| BMI, kg/m$^2$ | | < 0.001 | | < 0.001 | | 0.003 |
| < 21.5 (*n* = 42) | 45.3 ± 56.4 | | 89.1 ± 61.5 | | 19.3 ± 47.9 | |
| ≥ 21.5 (*n* = 42) | 169.2 ± 153.5 | | 222.5 ± 166.0 | | 66.9 ± 88.0 | |
| Mastectomy type | | 0.128 | | 0.251 | | 0.644 |
| SSM (*n* = 26) | 139.9 ± 140.8 | | 182.4 ± 158.5 | | 48.8 ± 75.0 | |
| NSM (*n* = 58) | 92.8 ± 124.6 | | 143.9 ± 132.7 | | 40.6 ± 74.6 | |
| Implant location | | 0.588 | | 0.450 | | 0.951 |
| Subpectoral (*n* = 51) | 113.6 ± 148.7 | | 165.3 ± 155.2 | | 42.7 ± 71.8 | |
| Prepectoral (*n* = 33) | 97.7 ± 98.2 | | 141.3 ± 117.7 | | 43.7 ± 79.4 | |
| Implant type | | 0.027 | | 0.043 | | 0.641 |
| Allergan (*n* = 42) | 76.8 ± 128.5 | | 123.6 ± 130.4 | | 35.9 ± 77.9 | |
| Bellagel (*n* = 8) | 71.7 ± 99.6 | | 127.5 ± 143.2 | | 58.2 ± 59.5 | |
| Mentor (*n* = 34) | 153.4 ± 129.3 | | 202.4 ± 145.0 | | 48.5 ± 73.9 | |

*MG* mammography, *MRI* magnetic resonance imaging, *SSM* skin-sparing mastectomy, *NSM* nipple-sparing mastectomy

Data presented as mean ± standard deviation. Mean differences calculated as mean values of relative difference obtained by subtracting implant size from the breast volume at MG or MRI measurements. MG- and MRI-based breast volume estimates, cm$^3$, implant volume, cc

calculate breast volume on the basis of a derived mathematical formula. Although it is easy to perform with the patient in the standing-up position, it is still subjective and its accuracy is often limited because of the broad individual variability in breast shapes.[26] Imaging is one of the objective methods used to assess breast volume because it replicates breast shape while allowing measurements. It involves various modalities, including MG,[27, 28] two-dimensional photography,[29] ultrasound,[30] computed tomography,[31] MRI,[14] and 3D laser scanners.[26, 32]

Among these imaging modalities, MG is generally included in a preoperative protocol for breast cancer surgery. Although MRI is not a routine protocol, it is considered as a gold standard for breast volume assessments as it allows us to differentiate chest wall versus breast tissue and to segment breast-specific regions on axial slices. Kim et al. found that mean implanted breast volume was closely related to mean MRI breast volume (correlation coefficient 0.893) in 30 patients with two-staged reconstruction surgery after the use of tissue expander.[13] Yoo et al. found that MRI breast volume yielded a significant correlation with mastectomy specimen weight for 99 patients who underwent a total mastectomy without reconstruction.[14] In this study, we focused on patients with one-stage (direct-to-implant) reconstruction, wherein the determination of implant size should be made during the surgery. The difference between the MRI breast volume and implant size was higher (155.9 cm$^3$) compared with those with total mastectomy in previous report (19 cm$^3$). This is because the substantial volume used for the skin flap occupied the breast after surgery. This gap seems to be related to the fact that a greater difference between MRI

**TABLE 3** Univariable linear regression analysis for implant size

| Variable | β | Standard error | P-value |
|---|---|---|---|
| Age, years | 2.1 | 1.3 | 0.126 |
| Height, cm | −0.3 | 1.7 | 0.881 |
| Body weight, kg | 8.6 | 1.2 | < 0.001 |
| Mastectomy type | −18.9 | 20.9 | 0.370 |
| Implant location | −35.9 | 19.5 | 0.069 |
| Implant type* | 67.9 | 18.4 | < 0.001 |
| MG breast volume, $cm^3$ | 0.4 | 0.02 | < 0.001 |
| MRI breast volume, $cm^3$ | 0.4 | 0.02 | < 0.001 |

*MG* mammography, *MRI* magnetic resonance imaging

*Implant type was categorized into binary groups; Allergan or Bellagel versus Mentor

**TABLE 4** Multivariable linear regression analysis for implant size

| Modality | Variable | β | Standard error | P-value |
|---|---|---|---|---|
| MG | Allergan or Bellagel ($n$ = 50) | | | |
| | Body weight | 2.1 | 1.4 | 0.143 |
| | Breast volume | 0.4 | 0.04 | < 0.001 |
| | Mentor ($n$ = 34) | | | |
| | Body weight | 1.6 | 1.4 | 0.259 |
| | Breast volume | 0.3 | 0.05 | < 0.001 |
| MRI | Allergan or Bellagel | | | |
| | Body weight | 3.2 | 1.2 | 0.010 |
| | Breast volume | 0.3 | 0.04 | < 0.001 |
| | Mentor | | | |
| | Body weight | 0.4 | 1.4 | 0.782 |
| | Breast volume | 0.3 | 0.05 | < 0.001 |

*MG* mammography, *MRI* magnetic resonance imaging

breast volume and implant size is found in patients with higher body weight than those with lower body weight. Patients with obesity tend to have higher skin flap volume because it usually contains subcutaneous fat tissue which is usually thicker in patients with higher body fat, and undermining the skin flap from the glandular tissue is often unclear in obese patients.

It should be noted that breast volume measured by imaging (either MRI or MG) can be more or less accurate in predicting implant size according to the surgical technique employed. As aforementioned, the type of breast surgery can impact the implant size because the extent of residual breast tissue is variable. Besides, in patients who undergo implant reconstruction for breast augmentation with no breast resection, the gap between imaging-based breast volume measurement and implant size would be higher than in patients with breast resection because the whole breast tissue is maintained after the reconstruction operation. Even in the group with certain type of breast surgery, there is a variation in the implant type (e.g., anatomical versus round shape) and surgical techniques, including the determination of resection margin that also would be associated with the resected breast tissue volume, and subsequently the implant size. In addition, the patient's breast volume and other profile, including body weight, can also affect the determination of implant type. In our study, for example, specific implant type seemed to be more selected in lean patients with thin skin, possibly due to rippling of the mastectomy skin flap from its softness (Table 1). Last but not least, the determination of implant size is necessarily related to patient preference. The results of this study could be translated to patients who may want to have their reconstructed breast similar to the contralateral breast because the implant was employed to fit the size

**TABLE 5** Distribution of breast volume, specimen weight, and implant size

| Breast volume, $cm^3$ | N | Specimen weight*, g | Implant size*, cc |
|---|---|---|---|
| < 100 | 3 | 89.3 ± 34.0, 108 (50, 110) | 116.6 ± 23.6, 125 (90, 135) |
| 100–200 | 13 | 185.8 ± 100.8, 164 (93, 502) | 152.6 ± 48.7, 135 (120, 300) |
| 200–300 | 20 | 250.7 ± 74.5, 240 (136, 403) | 225.5 ± 47.1, 220 (170, 320) |
| 300–400 | 26 | 279.5 ± 73.4, 269 (165, 465) | 244.8 ± 43.2, 238 (170, 370) |
| 400–500 | 6 | 419.5 ± 53.3, 425 (320, 477) | 322.5 ± 26.5, 335 (270, 340) |
| 500–600 | 5 | 370.4 ± 37.1, 359 (320, 477) | 330.0 ± 41.0, 300 (300, 375) |
| 600–700 | 4 | 411.5 ± 105.5, 425 (271, 525) | 376.2 ± 69.4, 393 (280, 440) |
| 700–800 | 5 | 480.4 ± 87.3, 433 (410, 624) | 387.0 ± 39.1, 410 (335, 420) |
| 800–900 | 1 | 700, 700 (700, 700) | 460, 460 (460, 460) |
| 900–1000 | 0 | N/A | N/A |
| > 1000 | 1 | 709, 709 (709, 709) | 470, 470 (470, 470) |

*N/A* not applicable

Breast volume was measured by using the mammography software Volpara

*Data presented as mean ± SD, median (range) of the contralateral breast. However, asymmetry could occur after reconstruction surgery below our expectation, in which case bias can arise in the implant size. An important caveat of our study was, first, that the enrolled patients were all Asian. Thus, direct generalization of the results is limited. It is expected that greater differences between MG or MRI breast volume and implant size will occur in Western women, who often have larger breasts. Second, sample sizes for each type of implant were not balanced, and the number of patients with Bellagel was too small. Thus, we conducted group analysis with the type of implant. Due to the population size of the study, generalization of our results may be weakened in patients with very small or large breast. Third, the reproducibility of MG breast volume was not demonstrated even though the intra-individual variability of MG examination according to several factors (positioning, MG unit, etc.) may impact the breast volume measurements and a considerable variability was found in breast density in short-term serial MGs in a previous study.[33] However, as the mammograms were performed using a single MG unit with the same protocol throughout this study period, variability according to MG unit could be minimized. Fourth, the definition and rate of bilateral asymmetry were not determined preoperatively or postoperatively. However, with a retrospective review of medical record, no patient- or physician-reported cases were found to have clinically significant asymmetry after surgery. Further prospective study is warranted with post-operative MRI to establish the appropriate implant size as reference, which resulted in a good symmetry.

In conclusion, breast volume measured by MG with fully automated software can be used to predict the appropriate implant size in breast cancer patients who are planned to undergo direct-to-implant reconstruction in an efficient and objective manner.

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