Original Article

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Use of Three-Dimensional Surface Imaging to Measure Breast Volume in the Upright Position With Acceptable Accuracy

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ABSTRACT

Objective: The utility of three-dimensional surface imaging (3DSI) for measuring breast volume in the upright position has not been established.

Materials and Methods: First, the accuracy of 3DSI measurements was evaluated using plastic models with known breast volumes. Then, the breast volumes of 30 patients were measured using 3DSI in the upright position, computed tomography (CT) in the supine position, magnetic resonance imaging (MRI) in the prone position, and mammography (MMG) of the compressed breast. To determine the impact of 3DSI measurements, the correlation coefficients between 3DSI and CT, between MMG and CT, and between MRI and CT were calculated.

Results: The accuracy of 3DSI measurements was confirmed using plastic models. The correlation coefficients between 3DSI and CT, between MRI and CT, and between MMG and CT were 0.83, 0.997, and 0.84, respectively. Although the breast volume measured by 3DSI was closely associated with that measured by CT, this correlation was weaker than that between the MRI- and CT-measured volumes and comparable with that between the MMG- and CT-measured volumes.

Conclusion: 3DSI can be used to measure breast volume in the upright position with clinically acceptable accuracy for the evaluation of cosmetic surgical outcomes.

Keywords: Breast volume; three-dimensional surface imaging; magnetic resonance imaging; computed tomography; mammography

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Key Points

- Three-dimensional surface imaging (3DSI) can be used to measure breast volume in the upright position with clinically acceptable accuracy.
- The correlation coefficient between 3DSI-measured and computed tomography (CT)-measured breast volumes was 0.83.
- Breast volume measured by magnetic resonance imaging was 5% larger than that measured by CT.
- Mammography is a convenient tool to estimate breast volume.

Introduction

The increasing survival rates of breast cancer patients have shifted the focus of research toward the management and quality of life of survivors. While breast-conserving surgery (BCS) and breast reconstruction have minimal impact on survival outcomes, they play a vital role in subsequent patient satisfaction. Achieving optimal esthetic outcomes in these procedures improves the overall well-being of breast cancer survivors.

Breast volume is a critical factor influencing the esthetic results of both BCS and breast reconstruction. In BCS, the cosmetic outcome is largely determined by the ratio of tumor volume to the affected breast volume (1), with a ratio of 10% or lower being associated with favorable results (2). Similarly, in breast reconstruction, accurate breast volume measurement is essential for selecting the appropriate size of tissue expanders, prostheses, or donor tissue for autologous reconstruction (3).

There are several methods of measuring breast volume using preoperative diagnostic imaging modalities, including computed tomography (CT), magnetic resonance imaging (MRI), and mammography (MMG). However, the optimal method has not yet been determined. CT and MRI require the patient to be in the supine and prone positions, respectively, while MMG requires compression of the breast. As the cosmetic outcome of the breast is usually evaluated with the patients in the upright or sitting position, these methods likely do not reflect subjectively meaningful breast volume (4, 5).

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Desktop personal computers are now sufficiently powerful to allow the use of three-dimensional cameras and to easily process three-dimensional images. Hence, three-dimensional surface imaging (3DSI) may have a role in improving the esthetic outcomes of breast surgery. Some researchers have attempted to use three-dimensional cameras to evaluate the shape of the treated breast (6, 7).

In light of these studies, we attempted to clarify the impact of 3DSI on breast volume measurements using other methods. First, we evaluated and confirmed the accuracy of the 3DSI volume measurements using plastic models in which the breast volumes were measured by the water replacement method. Then, we measured the breast volumes of 30 women using 3DSI, CT, MMG, and MRI. We evaluated the relationship between 3DSI-measured breast volume and CT-measured breast volume, the latter of which is considered equivalent to the volume of a surgically resected specimen. The association of breast volume measured by 3DSI, MMG, or MRI and that measured by CT was evaluated. Using these data, the utility of 3DSI for breast volume measurement was assessed.

Materials and Methods

3DSI Measurement of Breast Volume and Its Validation Using Phantoms

The K3 3D camera system (Kiisya Corporation, Tokyo, Japan) was used in this study. This 3D camera produces three-dimensional images of the target object and this was used to measure breast volume according to the manufacturer's manual. When imaging the right breast, the camera is positioned 60 cm away from the patient and slightly to the patient's right from the front to scan the entire breast. Four points forming a quadrilateral that covers the entire breast were placed on the image (Figure 1a). The extracted breast image was then sectioned horizontally at 10 levels. The boundary of the breast was marked at each level (Figure 1b), and the posterior side was closed with a straight line. The areas of the enclosed figures were summed to calculate the breast volume. The skin of the breast, as well as subcutaneous fat tissue, was included in the breast volume.

Before the study, we conducted a performance evaluation of the accuracy of the K3 camera. We created plastic breast models with volumes of approximately 300, 500, and 900 mL, respectively. The volumes of these three models were measured precisely based on Archimedes' principle (the volume is equivalent to the volume of displaced water). Measurements were repeated 10 times in each of these models and the resulting volumes were compared with the volume of displaced water.

Patients

Female breast cancer patients who are participating in an ongoing study in which we are investigating the usefulness of 3DSI for BCS were recruited to the present study. All participants in the present study underwent BCS. Three-dimensional imaging data for both breasts were obtained before the operation. In addition to these data, we obtained the demographic characteristics of the participants, clinical and pathological features of the breast cancer, and MMG, CT, and MRI images. This study was approved by Nihon University Itabashi Hospital Ethical Review Board (approval no.: RK-220208-4, date: 10.02.2025). Our study was performed in accordance with the principles of the Declaration of Helsinki. We obtained written informed consent from all participants.

CT Measurement of Breast Volume

CT was performed to examine the area from the neck to the pelvic organs for screening for metastatic lesions. For CT imaging, patients were placed in the supine position. In general, contrast medium was not used. Osirix® (Pixemo SARL, Switzerland) was used to measure the breast volume by CT according to the software manual. Briefly, the CT data were imported into this software, the margins of the sectioned breast image were traced in each slice (Figure 2), and the breast volume was calculated by summing the values of the traced area and multiplying by a section interval of 5 mm. The breast margin was defined as the breast skin surface and the outside lines of the muscle and bones of the thorax.

Fujii et al. (8) demonstrated that breast volume measured by CT is closely related to the volume determined from mastectomy specimens.

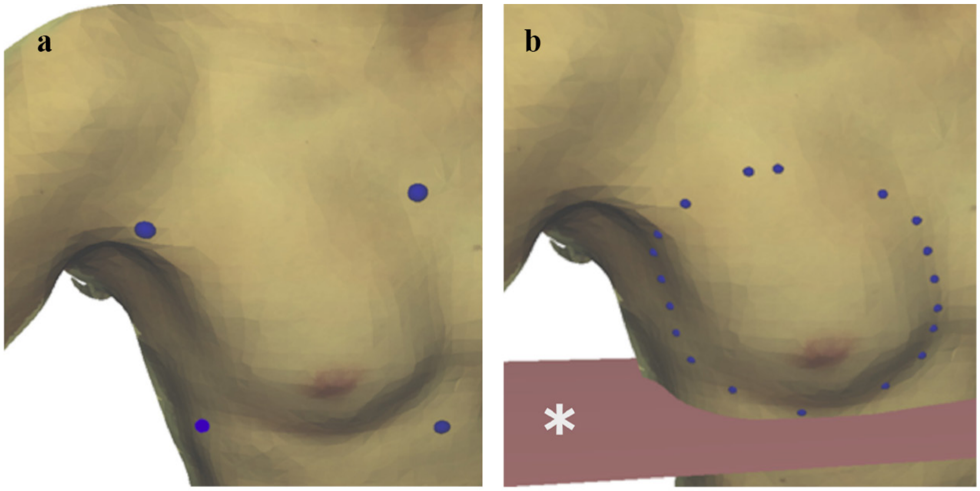

Figure 1. Measurement of the breast volume using 3DSI. Four points forming a quadrilateral covering the entire breast were placed on the image (Figure 1a). The extracted breast was then horizontally sectioned at 10 levels. The solid reddish-brown color with the symbol '*' indicates the section level (Figure 1b). The boundary of the breast was dotted at each level, and the posterior side was closed with a straight line. The areas of the enclosed figures were summed to calculate the breast volume

3DSI: Three-dimensional surface imaging

Based on this report, the CT volume was used as the benchmark in our study.

MRI Measurement of Breast Volume

MRI was performed to reveal the extent of the cancerous breast lesions and any unknown lesions. Patients were placed in the prone position. Contrast medium was used in all cases. The enhancement phase in MRI was not specified in the breast volume measurement. The procedure of breast volume measurement was the same as that for CT (Figure 3).

MMG Measurement of Breast Volume

The procedure for measuring breast volume by MMG was described by Cochrane et al. (2). Briefly, an MMG image is taken from the oblique lateral view shaped like a cone, denoting the breast (Figure 4). The distance from the upper to lower edges of the breast parenchyma is defined as the diameter of the cone base (2r). The distance from the nipple to the major pectoral muscle is regarded as the height of the cone (h). These values are used in the formula for calculating the volume of a cone to determine breast volume. The formula for the volume of a cone is volume = (1/3) $\pi r^2 h$.

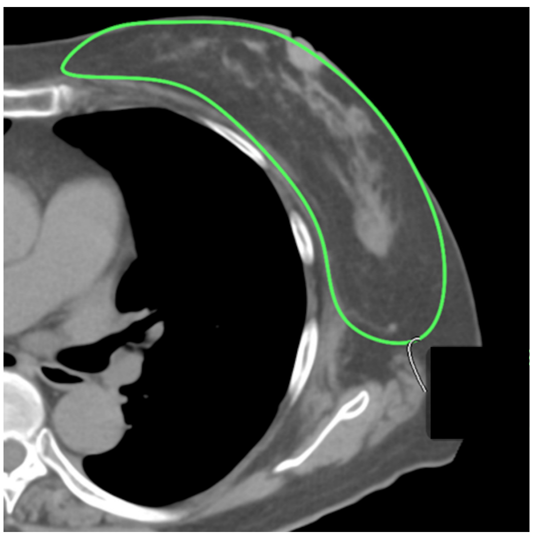

Figure 2. Measurement of the breast using CT. The margins of the sectioned breast image were traced in each slice (Figure 2), and the breast volume was calculated by summing the values of the traced area and multiplying by a section interval of 5 mm

CT: Computed tomography

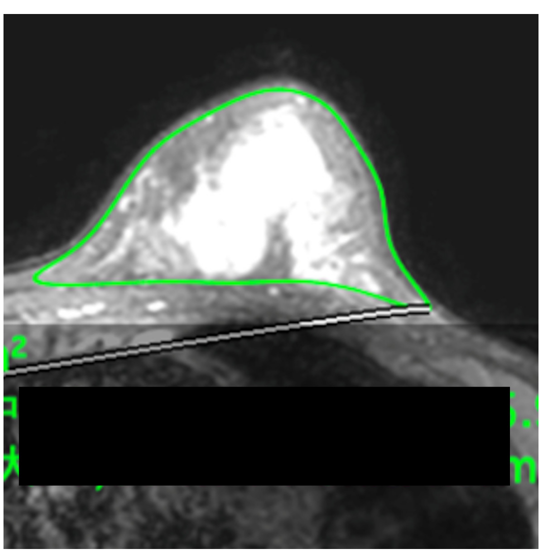

Figure 3. Measurement of breast volume using MRI. The margins of the sectioned breast images were traced in each slice (Figure 3). The measurement method using MRI is the same as that for CT. The MRI image is displayed upside down

MRI: Magnetic resonance imaging; CT: Computed tomography

Statistical Analysis

The relationship between two breast volume measurements was investigated using Pearson's correlation coefficients. Linear regression analysis was used to generate regression lines. The statistical package R v4.0.3 (R Foundation for Statistical Computing, Vienna, Austria; ISBN 3-900051-07-0; http://www.R-project.org) was used for the statistical analyses. A $p<0.05$ was considered significant.

Results

Reliability of 3DSI

The breast volume measurements using the plastic models for 3DSI validation are summarized in Table 1 and Figure 5. The volumes of these models were also measured according to Archimedes' principle. Based on these results, the measurement obtained by 3DSI was considered reliable, and we adopted the measured volume without calibration.

Demographic Characteristics of Participants

The characteristics of the 30 patients enrolled in this study are summarized in Table 2. The mean age, height, weight, and body mass index were 56.5 years, 161.8 cm, 58.4 kg, and 22.3 kg/m^2, respectively. Most patients (83.4%) had stage 0 or I disease. The mean tumor largest diameter measured by ultrasonography was 16.9 (range: 7.0–29.0) mm.

Although 60 breast volumes were studied, one data point for the unaffected breast volume measured by 3DSI was missing. Furthermore, two breast volumes were not measured by CT and MRI due to a

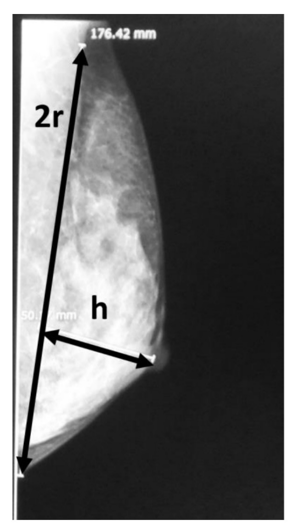

Figure 4. Measurement of breast volume by MMG from the oblique lateral view. The breast is regarded as a cone. The distance from the upper to lower edge of the breast parenchyma is defined as the diameter of the cone base (2r). The distance from the nipple to the major pectoral muscle is regarded as the height of the cone (h)

MMG: Mammography

history of breast surgery for the unaffected breast or elastic tape compression of the affected breast for post-biopsy hemostasis. Aside from these three cases, the breast shapes on both sides were comparable upon inspection. There were no cases of skin involvement or apparent skin retraction due to breast cancer.

Comparison of 3DSI, MRI, and MMG With CT for Breast Volume Measurement

The distributions of the breast volumes measured by CT, 3DSI, MRI, or MMG are summarized in Figure 6. The volume measured by MMG tended to be larger than the other measurements. Scatter diagrams of the breast volumes measured by 3DSI, MRI, and MMG versus CT are shown in Figure 7a, 7b, and 7c, respectively. Pearson's correlation coefficients for the breast volumes measured by 3DSI, MRI, or MMG versus CT were 0.83, 0.997, and 0.84, respectively (Table 3). Although the correlation coefficient for 3DSI versus CT was clinically acceptable, it was lower than that for MRI versus CT and comparable with that for MMG versus CT. When breast volume is estimated based on 3DSI measurements, the following formula should be used:

Estimated Breast Volume = (Breast Volume Obtained by 3DSI–128.7)/0.73

Notably, the breast volume measured by MRI was closely associated with that measured by CT (Figure 7b). In this comparison, the slope and *y*-intercept values were 1.05 and 8.5, respectively, indicating that the breast volume measured by MRI was 5% larger than that measured by CT.

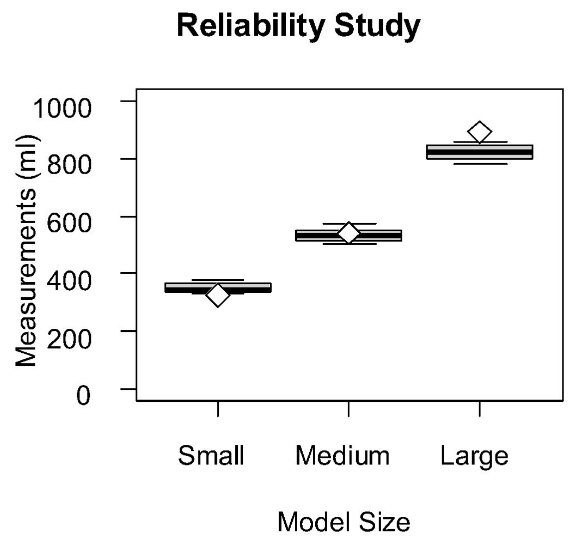

Figure 5. Measurements of three breast models using three-dimensional images. We created three plastic models of the breast with volumes of 300, 500, and 900 mL. We measured the volume of each breast model 10 times, and these results are summarized in box plots. The horizontal line in the box indicates the median size of the samples. The upper and lower ends of the box represent the 75th and 25th percentiles, respectively. The upper and lower ends of the whiskers represent the maximum and minimum values of the samples, respectively. The white diamond mark indicates the value measured based on Archimedes' principle

Table 1. Performance test of the K3 camera using models with three different breast volumes

	Median	Mean	Max	Min	SD	Archimedes method
300 mL size	346	351	382	328	18.8	326
500 mL size	532	534	576	504	21.0	541
900 mL size	823	820	859	779	27.8	892

Unit: mL; Min: Minimum; Max: Maximum; SD: Standard deviation

Table 2. Clinical characteristics of the 30 study patients

Characteristic		No. of cases or mean	Percentage or range
Mean age, years		56.5	(35–73)
Mean height, cm		161.8	(147.8–172.6)
Mean weight, kg		58.4	(44.6–82.9)
Mean body mass index		22.3	(17.7–31.4)
Laterality	Right	12	40%
	Left	18	60%
Stage	0	5	16.7%
	I	20	66.7%
	II	5	16.7%
Mean tumor size (range), mm§1		16.9	(7.0–29.0)

§1: The tumor size was measured by ultrasonography. One case was excluded because the lesion could not be measured by ultrasonography

Discussion and Conclusion

3DSI can be used to measure breast volume in the upright position with clinically acceptable accuracy. This conclusion is supported by the finding that the breast volumes measured by 3DSI and CT were moderately associated, with a correlation coefficient of 0.83, which was lower than that for MRI and comparable with that for MMG. The dorsal side of the breast on 3DSI consists of a flat plane, which is different from the true dorsal side of the breast. This is the probable reason why the correlation coefficient between the 3DSI- and CT-measured volumes was lower than that between the MRI- and CT-measured volumes.

3DSI may be used to measure breast volume in the upright or sitting position and thus enables evaluation of the visual cosmetic outcome (7). Therefore, 3DSI-determined breast volume may be useful as an indicator for esthetic purposes. Due to the moderate concordance between the 3DSI- and CT-measured volumes, 3DSI is useful for measuring breast volume, with clinically acceptable accuracy.

We used the breast volume measured by CT as a benchmark in this study for two reasons. First, CT clearly delineates the margin of the breast by revealing both the skin surface and dorsal margin of the breast. These clear margins lead to high reproducibility of the breast volume measurement. This high reproducibility is supported by the close association between the breast volume measured by CT and that measured by MRI, and these two techniques are similar in their measurement procedures except for the position of the patients. Second, a prior study reported that breast volume measured by CT is closely related to that determined from mastectomy specimens (8).

We found a close relationship between the breast volumes measured by MRI and CT. The regression line determined by Pearson's correlation analysis for the CT- and MRI-determined volumes had a slope of 1.05 and y-intercept of 8.5. Because this y-intercept value is significantly smaller than the whole breast volume, the volume measured by MRI is estimated to be 5% larger than the volume measured by CT. This

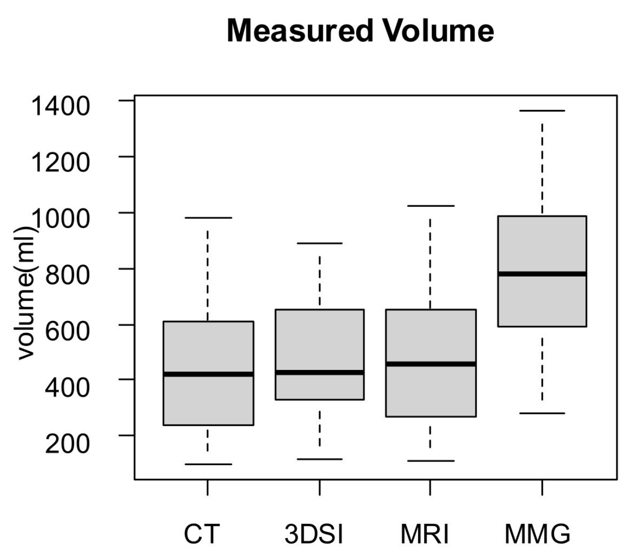

Figure 6. Boxplots showing the breast volumes measured by CT, 3DSI, MRI, and MMG

3DSI: Three-dimensional surface imaging; MRI: Magnetic resonance imaging; CT: Computed tomography; MMG: Mammography

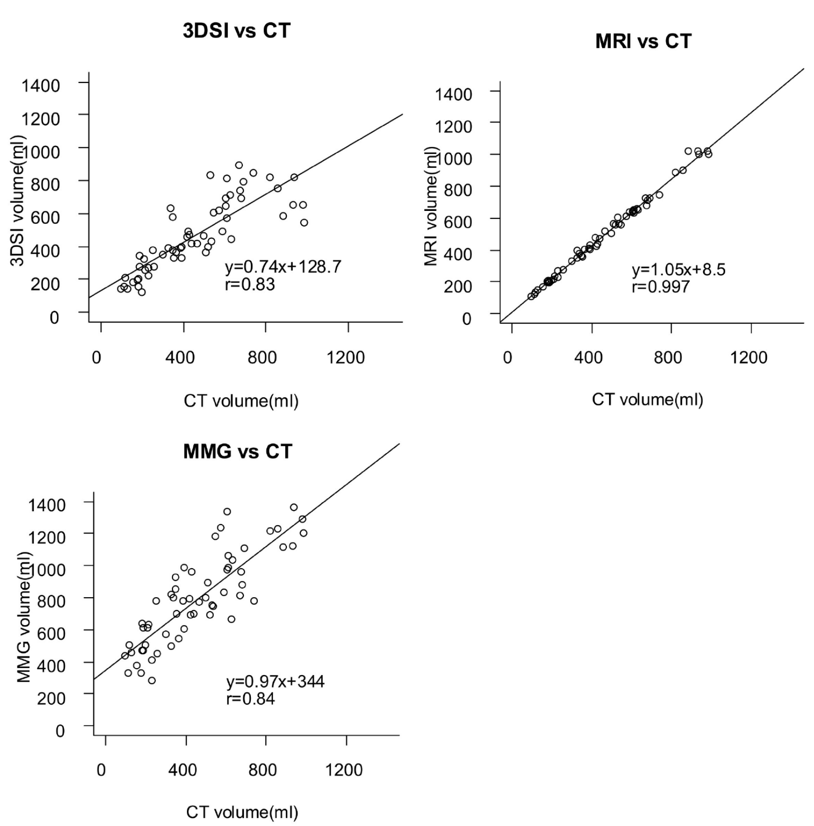

Figure 7. Scatter diagrams of breast volumes measured by 3DSI (Figure 7a), MRI (Figure 7b), and MMG (Figure 7c) *vs.* CT

3DSI: Three-dimensional surface imaging; MRI: Magnetic resonance imaging; CT: Computed tomography; MMG: Mammography

Table 3. Pearson's correlation coefficients for breast volume measured by 3DSI, MRI, or MMG *vs.* CT

Variables	Correlation coefficient	Slope	y-intercept	*p*-value
3DSI *vs.* CT	0.83	0.74	128.7	5.3×10^{-16}
MRI *vs.* CT	0.997	1.05	8.5	2.2×10^{-16}
MMG *vs.* CT	0.84	0.97	344.0	2.2×10^{-16}

3DSI: Three-dimensional surface imaging; MRI: Magnetic resonance imaging; CT: Computed tomography; MMG: Mammography

5% increase is attributable to the patient's posture during imaging; specifically, patients assume a supine position in CT studies and a prone position in MRI studies. A recent study has demonstrated that even arm positioning can affect breast volume (9). The only shortcoming of MRI and CT in this setting is that the measurements are time-consuming.

Our results suggest that breast volume measured by MMG is moderately different from that measured by CT or MRI. The correlation was weaker between the CT- and MMG-determined volumes than between the CT- and MRI-determined volumes. However, MMG is the most common and easy method of breast examination. We believe that the accuracy of breast volume measured by MMG is acceptable for daily practice (2).

Breast volume measurement is a promising area of study for the future. Beyond cosmetic evaluation in BCS or breast reconstruction, it is also used to predict oncologic factors, such as the likelihood of axillary lymph node metastasis (10) or the expression level of estrogen receptors (11). Furthermore, breast volume serves as an indicator for appropriate gender-affirming hormone therapy in transgender individuals (12).

Study Limitations

Our study has some limitations. All participants underwent BCS so there was no data on the volume of the whole breast specimen, which could be used as a benchmark for comparison. However, the lack of such data does not affect our conclusions because a previous study showed no difference in breast volume between CT measurements and mastectomy specimens (8). Thus, we used the breast volume measured by CT as the baseline volume in this study. Another limitation is that the range of the breast volume among our participants was 100–1,200 mL. Because some women have breast volumes of 2,000 mL or greater (2), our results may not apply to greater breast sizes. Further investigations are necessary.

3DSI can be used to measure breast volume in the upright position with clinically acceptable accuracy for evaluation of cosmetic surgical outcomes. 3DSI is a potential option for comparing breast volumes between the preoperative and postoperative breast for esthetic evaluation.

Ethics

Ethics Committee Approval: This study was approved by Nihon University Itabashi Hospital Ethical Review Board (approval no.: RK-220208-4, date: 10.02.2025).

Informed Consent: We obtained written informed consent from all participants.

Footnotes

Authorship Contributions

Surgical and Medical Practices: H.G., S.F., Y.H., K.T.; Concept: Y.H., K.T.; Design: K.T.; Data Collection or Processing: H.G., S.F.; Analysis or Interpretation: H.G., K.T.; Literature Search: Y.H., K.T.; Writing: K.T.

Conflict of Interest: No conflict of interest was declared by the authors.

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