The Breast (2007) **16**, 137–145

ELSEVIER

THE BREAST

www.elsevier.com/locate/breast

ORIGINAL ARTICLE

# Comparison between breast volume measurement using 3D surface imaging and classical techniques ☆

**Laszlo Kovacs[a,*], Maximilian Eder[a], Regina Hollweck[b], Alexander Zimmermann[a], Markus Settles[c], Armin Schneider[d], Matthias Endlich[a], Andreas Mueller[a], Katja Schwenzer-Zimmerer[e], Nikolaos A. Papadopulos[a], Edgar Biemer[a]**

[a]*Department of Plastic and Reconstructive Surgery, Klinikum rechts der Isar, Technical University Munich, Ismaninger strabe 22, D-81675 Munich, Germany*
[b]*Institute of Medical Statistics and Epidemiology, Klinikum rechts der Isar, Technical University Munich, Ismaningerstr. 22, 81675 Munich, Germany*
[c]*Department of Radiology, Klinikum rechts der Isar, Technical University Munich, Ismaningerstr. 22, 81675 Munich, Germany*
[d]*Workgroup for Minimally Invasive Therapy and Intervention–MITI of Technical University Munich, Department of Surgery, Klinikum rechts der Isar, Technical University Munich, Ismaningerstr. 22, 81675 Munich, Germany*
[e]*Center of Advanced Studies in Cranio-Maxillo-Facial Surgery, Department of Reconstructive Surgery, Division of Cranio-Maxillo-Facial Surgery, University of Basel, Spitalstrasse 21, 4031 Basel, Switzerland*

Received 18 March 2006; received in revised form 4 June 2006; accepted 9 August 2006

**KEYWORDS**
Breast;
Volume;
Three-dimensional imaging;
3D scan

**Summary** Quantification of the complex breast region can be helpful in breast surgery, which is shaped by subjective influences. However, there is no generally recognized method for breast volume calculation. Three-dimensional (3D) body surface imaging represents a new alternative for breast volume computation. The aim of this work was to compare breast volume calculation with 3D scanning and three classic methods, focusing on relative advantages, disadvantages, and reproducibility. Repeated breast volume calculations of both breasts in six patients ($n = 12$) were performed using a 3D laser scanner, nuclear magnetic resonance imaging (MRI), thermoplastic castings, and anthropomorphic measurements. Mean volumes (cc) and mean measurement deviations were calculated, and regression analyses were performed. MRI showed the highest measurement precision, with a mean deviation (expressed as a percentage of mean breast volume) of $1.56 \pm 0.52\%$

☆Part of this work was presented at the Annual Meeting of the German Association of Plastic Surgeons (VDPC) in Munich, Germany, held between September 28 and October 1, 2005.

*Corresponding author. Tel.: +49 89 4140 5073; fax: +49 89 4140 7399.
*E-mail address:* l.kovacs@lrz.tum.de (L. Kovacs).

0960-9776/$ - see front matter 
doi:10.1016/j.breast.2006.08.001

compared with 2.27±0.99% for the 3D scanner, 7.97±3.53% for thermoplastic castings, and 6.26±1.56% for the anthropomorphic measurements. Breast volume calculations using MRI showed the best agreement with 3D scanning measurement ($r = 0.990$), followed by anthropomorphic measurement ($r = 0.947$), and thermoplastic castings ($r = 0.727$). Compared with three classical methods of breast volume calculation, 3D scanning provides acceptable accuracy for breast volume measurements, better spatial interpretation of the anatomical area to be operated on (due to lack of chest deformation), non-invasiveness, and good patient tolerance. After this preliminary study and further development, we believe that 3D body surface scanning could provide better preoperative planning and postoperative control in everyday clinical practice.


## Introduction

A primary objective of all breast surgeries is breast symmetry. Quantification of breast volume may be helpful in obtaining optimal results.[1,2] However, in everyday clinical life breast volume measurements are not routinely accomplished because thus far no generally recognized method of volume calculation exists.[3] Generally, these methods of breast volume assessment fall into one of five different categories.

The anthropomorphic method attempts to derive a correlation between breast volume data obtained by other methods and standardized end-to-end measurements of the thorax region.[4,5] As an alternative, with modified anthropomorphic methods the breast volume is equated to a half-ellipse and the parameters of the mathematical formula of a half-ellipse are measured directly at the patient or indirectly from a two-dimensional (2D) photograph of the breast region.[6,7]

Volume methods based on the basis of 2D images such as mammograms and ultrasound are somewhat comparable to modified anthropomorphic measurement with the help of 2D photography.[8,9] Geometric parameters (e.g., partial ellipse) are projected onto the 2D image or individual ultrasonic layers and the breast volume is calculated using the appropriate mathematical formulas.

Archimedean methods of breast volume measurement are based on Archimedes' principle of water displacement.[10,11] The female patient bends over a water-filled vessel, lowering her breast into the water, and breast volume is calculated based on displaced water. Alternatively, modified methods use calibrated measurement cylinders placed against the thorax wall; the rigid thorax wall forms the rear demarcation of the breast and the ventral tissue portions are measured as the displaced "breast volume."[12–14]

Another method is the use of plaster and thermoplastic materials to generate a three-dimensional (3D) negative cast of the breast.[15,16] The cast materials are placed on the upright, seated patient and left to harden. The resulting 3D shell model is filled with water or sand in order to determine breast volume.

Modern imaging procedures such as computed tomography (CT) and nuclear magnetic resonance imaging (MRI) offer an alternative means of modeling the breast in 3D.[17,18] The patient is placed in the scanner in a prone position, and the breast volume is calculated by the summation of segmented monolayers.

An alternative to these classical methods is 3D body surface imaging. With the help of different 3D imaging devices, a non-invasive recording in a standing position and the creation of a virtual 3D model of the breast region are possible. Furthermore, the 3D technology provides the ability to quantitatively evaluate symmetry, volume, shape, contour, surface, and distance measurements.[2,19–26] However, no comparisons have been made between breast volume calculations using 3D imaging versus other methods; cross-comparisons of the classic volume computation methods are themselves uncommon.[3,27]

Based on the results of our preparatory studies,[2,21,22,28] the focus of this work was to preliminarily assess the potential of 3D surface scanning in relation to the existing methods of breast volume computation by performing a critical analysis of the advantages and disadvantages of each method with special emphasis on the reproducibility and inter-correlation of the individual methods.

## Materials and methods

The breast volumes ($n = 12$) of a homogeneous group of six test subjects (mean age 27±1.86 years, mean body mass index 20±1.17 kg/m$^2$, and mean sternal notch to nipple distance $20.41 \pm 1.82$ cm) were measured by one observer with four different methods and the results compared.

## 3D laser scanner

3D breast imaging was performed with the test participants standing and arms down using a Minolta Vivid 910 3D linear laser scanner (Konica-Minolta, Osaka, Japan) according to a standardized 3D scanning protocol.[22] Applying the protocol developed in our lab,[28] one observer performed ten measurements per breast, per participant ($n = 120$) and calculated breast volumes in cc using the Raindrop Geomagic Studio 7 software (Raindrop Geomagic, Durham, NC, USA; Fig. 1).

## Nuclear magnetic resonance imaging

Test participants were positioned prone in a 1.5T Philips Intera Upgrade R7 MR scanner (Philips Medizin Systeme, Hamburg, Germany) for MRI. No contrast medium was used. Analogous to the procedure described by Mineyev et al.,[29] volume computation was accomplished with a 3-mm layer thickness using Easy Vision 4.0 software (Philips Medizin Systeme, Hamburg, Germany). Imaging and ten volume computations per breast and participant ($n = 120$) were performed by one observer under the guidance of an experienced radiological specialist. Manual segmentation of the tissue portions was performed in each ventral monolayer along the outside breast form and on the dorsal aspect of the pectoral muscle (Fig. 2a).

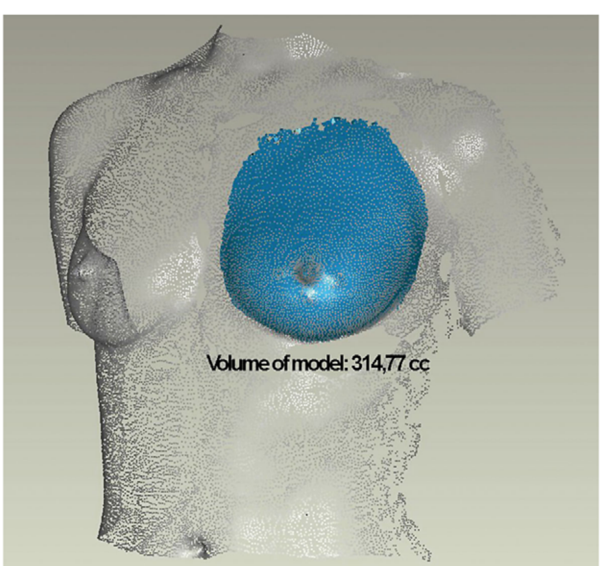


**Figure 1** Creation of a closed volume model, which represents the breast volume in cc using a 3D scanner.

Monolayers were totaled to obtain the total breast volume in cc.

## Thermoplastic casts

Analogous to the published method of Edsander-Nord et al.,[16] a thermoplastic cast of each test participant's breast region was taken in an upright, seated position and evaluated (Orfit Classic Soft; Orfit Industries, Wijnegem, Belgium). With this method, a flat dorsal delimitation was created by aligning the female (negative) cast form on the horizontal, filling it up with water, and measuring the water volume in millimeters (ml = cc); breast volume above this delimitation was not included in the calculation (Fig. 3). The examiner performed ten determinations of breast volume per thermoplastic casting ($n = 120$). The deformation of the breast shape during the molding process was analyzed.

## Anthropomorphic methods

Breast volumes of the six test participants were computed using the formula published by Qiao et al.[6]: $1/3\pi \times \mathrm{MP}^2 \times (\mathrm{MR+LR+IR-MP})$. MR corresponds to the distance between the nipple and medial breast border, LR to the distance between the nipple and lateral breast border, IR to the distance between the nipple and inframammary fold, and MP to the mammary projection, which was measured by viewing the test participant from the lateral aspect from sternum to nipple (Fig. 4). Thus, breast volume was computed in cc over a half-ellipse (Fig. 2d). Measurements were made manually ten times per participant, per breast ($n = 120$).

With the formula introduced by Brown et al.,[7] the resection weight in cc of five female breast reduction patients (age: $40.20 \pm 10.59$ years, body mass index: $25.79 \pm 2.16\ \mathrm{kg/m^2}$, average sternal notch–nipple distance: $28.13 \pm 2.43$ cm) was predicted before surgery. A half-ellipsoid was projected onto a preoperative 2D photograph of a female patient in order to define the parameters ($A$, $B$, and $C$) needed for computation of the formula (Fig. 4). Next, the postoperative result targeted by the surgeon was drawn in and the corresponding necessary parameters computed ($A'$, $B'$, and $C'$). With the help of the formula $\Delta V = (\pi/6)\alpha(ABC - A'B'C')$, the breast volume changes in cc were predicted by one observer and compared with the intraoperative resection weight (g, assumed mass density of $1\ \mathrm{g/cm^3}$).[30] Additionally, the predicted breast volume changes were compared with the results of our study performed with the same patients in which the difference

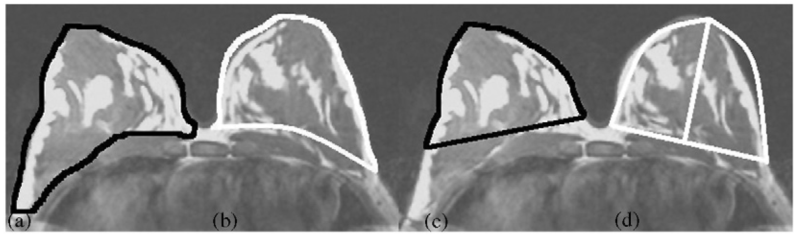


**Figure 2** Example of breast volume areas measured in cc using the four different techniques. Measured areas are indicated by black and white lines on the two identical images: (a) MRI, (b) 3D scanning, (c) thermoplastic casts, and (d) modified anthropomorphic measurement with half-ellipse.

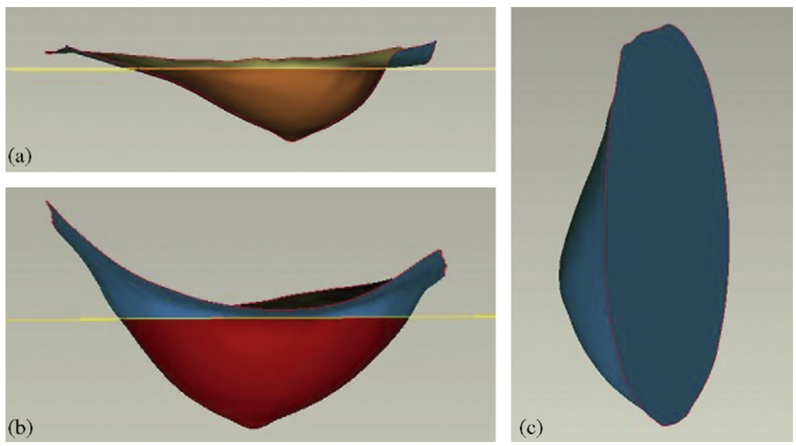


**Figure 3** Delimitation of breast volume measurement (cc) with thermoplastic cast: (a) inner breast view, (b) caudal view, and (c) resulting dorsal planar boundary.

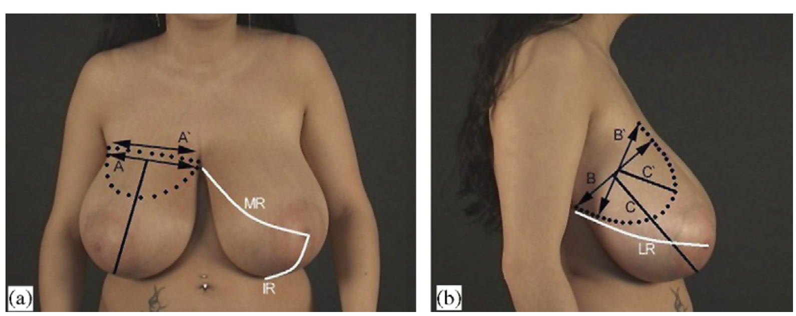


**Figure 4** Breast volume measurement procedures (cc) using anthropomorphic measurement (white lines) and 2D photography (black lines). (a) MR = distance between nipple and medial border, IR = distance between nipple and inframammary fold, and (b) LR = distance between nipple and lateral border. (a) $A$ = the ellipsoidal width, front view, (b) $B$ = the ellipsoidal height, and $C$ = the ellipsoidal semiaxis, lateral view; $A'$, $B'$, and $C'$ = the corresponding measurements on the predicted postoperative breast.

between pre- and postoperative breast volume (cc) was calculated with the help of the 3D scanning method.[28]

## Statistical analysis

Each test participant's ten replicate breast volume measurements were aggregated separately for each breast as a mean volume in cc. The coefficient of variation (CV = 100 × standard deviation/mean) was expressed as a percentage of mean breast volume to evaluate reproducibility. Dependency on the volume of the right and left breasts of one test participant was not considered in the testing procedures. To investigate possible relationships among the four breast volume measurement procedures, the Pearson coefficient of correlation was computed and a linear regression analysis was performed. All tests were two-tailed using a significance level of $P<0.05$ and were performed using SPSS version 13 software (SPSS, Chicago, IL, USA).

## Results

The mean breast volumes for each individual test participant by measurement method are presented in Table 1, which also shows the mean breast volume (cc) across test participants and the mean measurement deviation (expressed as a percentage of mean volume) for each method. Figure 2 depicts a comparative representation of breast areas computed with the different methods, overlaid on two identical MRI tomography images.

### 3D laser scanner

The 3D scanning method yielded a mean breast volume across all test participants of $452.51 \pm 141.88$ cc, and a measurement deviation of $2.27 \pm 0.99\%$ of the measured breast volumes (Table 1). The breast volume determined by the 3D scanner is represented in Fig. 2b.

### Nuclear magnetic resonance imaging

Our comparison of measurement techniques showed that in contrast to 3D scanning, MRI measurement determined the entire breast volume according to the real anatomical structures (Fig. 2a). With the MRI method, the mean breast volume increased to $582.27 \pm 184.71$ cc and a higher measurement precision with a deviation of $1.56 \pm 0.52\%$ of the mean breast volume was obtained (Table 1).

### Thermoplastic casts

Breast volumes determined by means of thermoplastic casts differed substantially from those determined by 3D scanning (Fig. 2c, Table 1). The mean breast volume across test participants was $440.18 \pm 112.56$ cc, smaller than that reported for 3D scanning. The measurement deviation, $7.97 \pm 3.53\%$ of the mean volume, was higher than that for 3D scanning, indicative of lower measurement precision (Table 1).

### Anthropomorphic measurement

The mean breast volumes within participants and across participants determined using the formula described by Qiao et al.[6] are presented in Fig. 4 and Table 1. The mean breast volume across all test participants was $445.20 \pm 192.08$ cc. A mean measurement deviation of $6.26 \pm 1.56\%$ of mean breast volume was calculated (Table 1).

The predicted average breast volume change using the formula by Brown et al.[7] of the five female breast reduction patients was $559.06 \pm 259.44$ cc with a mean measurement deviation of $5.54 \pm 1.50\%$ of the mean breast volume. The average resection weight was $600.53 \pm 441.67$ cc, and the calculated volume difference using 3D surface imaging was $600.48 \pm 460.55$ cc with a mean deviation of $2.47 \pm 0.52\%$ preoperatively and $1.34 \pm 0.23\%$ postoperatively ($P<0.001$).[28]

**Table 1** Test participants' breast volume assessments ($n = 12$) with the four different measurement techniques.

| Test persons | 3D scan | MRI | Thermoplastic casts | Anthropomorphic measurement |
|---|---|---|---|---|
| *Mean volume+S.D. (cc)* | | | | |
| 1 | 311.50±2.40 | 420.70±1.56 | 366.50±16.26 | 267.60±67.46 |
| 2 | 570.80±4.81 | 758.60±9.33 | 457.00±4.24 | 503.90±46.53 |
| 3 | 231.90±21.35 | 292.30±29.27 | 186.50±32.47 | 133.80±25.46 |
| 4 | 460.20±4.24 | 560.60±3.11 | 421.00±79.20 | 529.60±2.83 |
| 5 | 566.40±9.05 | 709.30±28.14 | 464.00±41.01 | 605.20±67.46 |
| 6 | 574.25±6.15 | 75210±10.04 | 517.50±60.10 | 631.10±25.46 |
| Mean | 452.51±141.88 | 582.27±184.71 | 440.18±112.56 | 445.20±192.08 |
| *Mean deviation (S.D.) in percentage of volume+S.D. (%)* | | | | |
| Mean | 2.27±0.99 | 1.56±0.52 | 7.97±3.53 | 6.26±1.56 |

Mean breast volumes (cc) within and across test participants and mean deviations (expressed as a percentage of mean breast volume (%)) are shown.

## Correlations among the four breast volume measurement techniques

In spite of using four different recording methods (Fig. 2), the mean breast volumes showed a generally similar pattern across participants (Table 1).

A comparison of the coefficients of correlation ($r$) for the four methods (Table 2) revealed that MRI showed the best agreement with 3D scanning ($r = 0.990$, $P < 0.001$), followed by the anthropomorphic method ($r = 0.947$, $P < 0.001$), and thermoplastic casts ($r = 0.727$, $P = 0.017$).

To enable more direct comparison of the breast volumes determined with the individual methods, regression equations were calculated, which enabled conversion of all the measurement units into those used for 3D scanning (Fig. 5). The regression equations revealed the following relationships: (a) 3D scan $= 9.83 + 0.75 \times$ MRI, (b) 3D scan $= -47.69 + 1.22 \times$ thermoplastic casts, and (c) 3D scan $= 141.03 + 0.70 \times$ anthropomorphic measurement (all in cc).

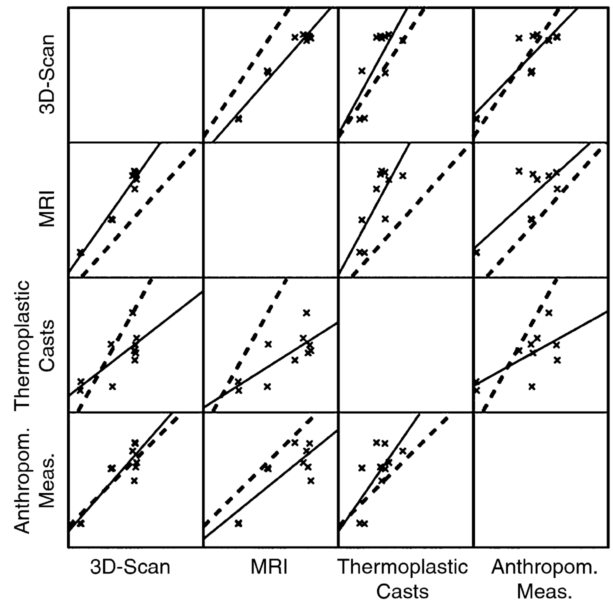


**Figure 5** Regression lines between breast volume measurements obtained from 3D scanning and three other techniques (broken line indicates identity line [results from linear regression through origin with slope = 1], continuous line indicates regression line).

## Discussion

From the viewpoint of the operating surgeon, determination of breast volume could be helpful and desirable to potentially facilitate the complex planning and difficult execution of many surgical breast interventions, including correction of breast asymmetry, restoration of an ablated breast, and volume-changing esthetic intervention.[1,2,6,7,20–26] The desire for improved breast volume calculation methods is reflected by over 50 publications in the last four decades on the topic. Unfortunately, the various breast volume measurement techniques that have been proposed in such articles exhibit variable reliability. Moreover, these techniques involve a level of detail that can be difficult to execute, they are of limited practicability, are often cost-intensive, and are not always accepted by the patient.[3] For these reasons, these techniques have found only limited application in everyday plastic and reconstructive surgery, and in only exceptional cases does breast volume measurement occur before surgery. Most methods of breast volume assessment can be categorized into one of the five groups described. Our own analysis shows that these different methods include different breast tissue components in volume computation (Fig. 2). This may partially explain the fact that we often found differences in the measured absolute volume values across the four methods analyzed.

With anthropomorphic methods, volumes are computed based only on individually measured values (end-to-end measurements), and a predefined geometrical shape is imposed on the breast form, which does not necessarily correspond to the individual anatomical conditions of the respective breasts. In light of these disadvantages, the mean measurement deviation in the literature, 3.61% of the volume measured reported by Westreich[5] and 3.89% by Qiao et al.,[6] is surprisingly small. In contrast, we determined a mean deviation of 6.26% of the mean volume, applying the formula described by Qiao et al.[6] With the help of a modified

**Table 2** Pearson correlation coefficients ($r$) and $P$ values for correlation analyses of the four different measurement techniques.

| | 3D scan | MRI | Thermoplastic casts |
|---|---|---|---|
| MRI | | | |
| $r$ | 0.990 | | |
| $P$ | 0.000 | | |
| Thermoplastic casts | | | |
| $r$ | 0.727 | 0.762 | |
| $P$ | 0.017 | 0.010 | |
| Anthropomorphic measurement | | | |
| $r$ | 0.947 | 0.914 | 0.669 |
| $P$ | 0.000 | 0.000 | 0.035 |

anthropomorphic method, Brown et al.[7] tried to anticipate the size of the resection weight before a breast reduction operation. The method involves projection of a half-ellipsoid onto a preoperative 2D photograph of a female patient (Fig. 4). We have applied this formula to five breast reduction patients and the mean error of our measurements with the applied formula was $5.54 \pm 1.50\%$ of the mean breast volume, which is comparable to the results of Brown et al.[7] Although these methods are relatively feasible, they have very low costs (tape measure, calculator, and working time) and can be accomplished with a standing patient, one must get used to the calculation formula in many cases and the methods require some subjective determinations because the limits are extremely arbitrary. This perception is assured by the fact that the mean internal variation of the manual measurements, numerically expressed by the standard deviation (S.D.), is the highest of all the methods analyzed (Table 1). In our preparatory work we analyzed the precision of manual measurements for specific anatomical distances of the breast region.[22] We found that the measuring variability increases with less anatomically well-defined landmarks or those that were located in the submammary region. In our opinion, the above-mentioned specific disadvantages of the anthropomorphic methods affect the reproducibility and show clearly that the measurements are dependent on the individual observer.

With regard to MRI, the breast volume calculation is based on actual anatomical structures. Fowler et al.[18] reported a mean deviation of 4.3% for MRI-based volume measurements. In our study we determined a mean deviation of $1.56 \pm 0.52\%$. Because of the easily recognizable landmarks we found that the manual segmentation was to be performed very precisely and the discrepancy with the above-mentioned results can only be explained by the improvement in the MRI imaging. MRI provides the most precise volume assessment method, although the most costly. Caruso et al.[31] analyzed that for a single volume measurement, the cost of the time and materials was $1400 for the MRI, which is too expensive for a routine preoperative breast volume measurement. In addition to the high costs and the time-consuming assessment of the results, another disadvantage of MRI is that deformation of the chest region is apparent on images taken in the supine position; the resulting 3D models do not correspond to the real anatomical shape of the breast and are of little help to the clinicians.

In the production of thermoplastic casts, the breast is deformed and pressed against the thorax wall. The extent of breast compression during production of a thermoplastic cast is shown in Fig. 6. Clearly apparent are areas of compressed tissue from the thermoplastic material, as well as cast areas shaped by material squeezed out from the thorax wall. The relatively inflexible thermoplastic material cannot perfectly model the breast form and is distorted under the manual pressure of the examiner. In addition, by filling up the casts with water or sand, the rear demarcation of the chest is defined as a flat level that connects the edges of the chest (Fig. 3). The breast portions above the flat rear wall are not included in the volume calculation, and the actual curvature of the breast wall is not considered; consequently, smaller volumes are computed. Thus, while an actual 3D breast volume is created (unlike with anthropomorphic methods), because the shape of the breast region is changed, the resulting volume calculation is problematic. Manual evaluation in particular is somewhat subjective. It is not clearly defined which line constitutes the rear delimitation of the cast. According to Edsander-Nord et al.,[16] the cast should be filled with water "until it reached two

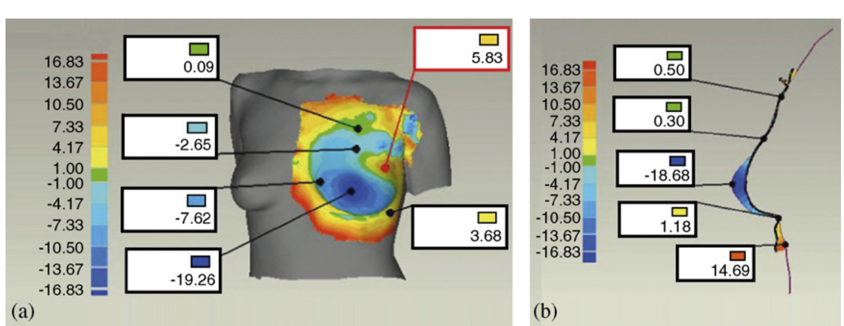


**Figure 6** Color-coded image demonstrating areas of breast compression during generation of thermoplastic casts; (a) colors are superimposed on the breast region and (b) sagittal slice with 2D deviation; scale is calibrated in millimeters. Blue regions indicate compressed areas and yellow to red areas indicate cast areas resulting from material squeezed out from the thorax wall.

opposite points of the delineated breast boundary". As shown in Fig. 6, the breast is compressed and the breast borders are thus not obvious and arbitrary. Therefore, we found it extremely difficult to perform the manual evaluation. In the literature, the precision of the breast volume calculation has been reported as being relatively constant with the thermoplastic cast method, with a deviation of 6%.[16] Our results show a deviation of 7.97% of the measured volume value. In addition to the high material costs of approximately $150 per breast, we found that the relatively inflexible thermoplastic material with the resulting deformation of the breast tissue and the difficult manual evaluation of the thermoplastic casts affect reproducibility and should be used with caution for breast volume assessment.

The advantages of breast volume computation using 3D scanning are objectively based on the fast and extensive recording of the breast region's surface geometry. A "virtual casting" is developed of the breast region. Unlike conventional methods such as gypsum or thermoplastic casting, the data recording takes place without body contact. Thus, data can be collected without deformation of the breast and with the patient in an upright standing position.[22] However, as is the case with conventional castings of the breast region, the rear demarcation of the volume area that can be measured is not obtained. In contrast to the classical methods, where the curvature of the thorax wall can be approximately modeled only by exerting pressure against the thorax wall, it is possible to correctly compute the thorax wall curvature with the help of special software.[21] This computed rear demarcation plane runs parallel to the anatomical breast wall curvature and sufficiently accurate breast volume measurements are possible.[2,22,24,28] Besides the advantages there are still the technical obstacles, the sometimes time-consuming analysis, and the high costs of this new technology to overcome in the future.[32] There is a wide variety of available 3D surface imaging systems and appropriate software applications, which differ enormously in cost and quality. Therefore, it is difficult to make a universally valid statement concerning the cost effectiveness of 3D surface imaging technology. But we believe that the development of 3D scanning systems in the last few years and the improvement in clinical applications will make this technology more user-friendly, more affordable with regard to compact application packages, and will one day be established in the everyday life of plastic surgeons, similar in cost and applicability to the currently used 2D digital photography systems.[33]

The calculated regression equations can assist in comparing the absolute values of the individual volume calculation methods. We used regression analysis to explore the optimal methods of volume measurement that can be accomplished simply and favorably—the gold standard of 3D measurement. A straight line was used as an interpolation function that showed a good approximation of the data. The regression lines showed in many cases clear deviations from the reference lines; the data of thermoplastic casting, in particular, revealed a strong dependence on the actual volume compared with the other methods. In this context, we have to admit that due to the limited sample size in this study our results have to be described as preliminary and further investigations are needed.

## Conclusions

Our analysis has shown that the four breast volume calculation methods considered take into account different areas of breast tissue (Fig. 2). Since these different methods measure different breast volume areas, a comparison is possible only at the level of measurement precision.

In summary, the 3D scanner represents a simple and promising method. Based on the determined measurement precision,[28] and the characteristic relationships to the other recognized methods we have shown here, there is reason to believe that this technology—in spite of the existing technical obstacles and only preliminary results in comparison to other breast volume measurement techniques—could contribute to the establishment of routine breast volume measurements in everyday plastic and reconstructive surgery after further clinical investigations and technical development.

## Acknowledgments

The authors are grateful to Prof. Dr. E.J. Rummeny, Director of the Department of Radiology and Prof. Dr. H. Feussner, Clinical Head of the Workgroup for Minimally Invasive Therapy and Intervention (MITI), Department of Surgery, both Technical University of Munich, Germany, for their cooperation and infrastructural support, which contributed enormously to the realization and success of this study.

The authors also thank Prof. Dr. H.F. Zeilhofer, Director of the Department of Reconstructive Surgery, Division of Cranio-Maxillo-Facial Surgery, University of Basel, Switzerland and Prof. Dr. R. Sader, Department of Cranio-Maxillo-Facial and Facial Plastic

Surgery, J.W. Goethe University, Frankfurt am Main, Germany for the continuous support of our projects and for the provision of the infrastructure that has enabled this study to be carried out. The authors would also like to thank Mr. Marco Zajac, German representative of Minolta Co., Ltd., Osaka, Japan, for his long-standing support of our research projects.

## References


1. Hudson DA. Factors determining shape and symmetry in immediate breast reconstruction. *Ann Plast Surg* 2004;**52**:15–21.
2. Kovacs L, Zimmermann A, Papadopulos NA, et al. Re: factors determining shape and symmetry in immediate breast reconstruction. *Ann Plast Surg* 2004;**53**:192–4.
3. Bulstrode N, Bellamy E, Shrotria S. Breast volume assessment: comparing five different techniques. *Breast* 2001;**10**: 117–23.
4. Smith Jr. DJ, Palin Jr. WE, Katch VL, et al. Breast volume and anthropomorphic measurements: normal values. *Plast Reconstr Surg* 1986;**78**:331–5.
5. Westreich M. Anthropomorphic breast measurement: protocol and results in 50 women with aesthetically perfect breasts and clinical application. *Plast Reconstr Surg* 1997; **100**:468–79.
6. Qiao Q, Zhou G, Ling Y. Breast volume measurement in young Chinese women and clinical applications. *Aesthetic Plast Surg* 1997;**21**:362–8.
7. Brown RW, Cheng YC, Kurtay M. A formula for surgical modifications of the breast. *Plast Reconstr Surg* 2000;**106**: 1342–5.
8. Kalbhen CL, McGill JJ, Fendley PM, et al. Mammographic determination of breast volume: comparing different methods. *Am J Roentgenol* 1999;**173**:1643–9.
9. Malini S, Smith EO, Goldzieher JW. Measurement of breast volume by ultrasound during normal menstrual cycles and with oral contraceptive use. *Obstet Gynecol* 1985; **66**:538–41.
10. Bouman FG. Volumetric measurement of the human breast and breast tissue before and during mammaplasty. *Br J Plast Surg* 1970;**23**:263–4.
11. Schultz RC, Dolezal RF, Nolan J. Further applications of Archimedes' principle in the correction of asymmetrical breasts. *Ann Plast Surg* 1986;**16**:98–101.
12. Kirianoff TG. Volume measurements of unequal breasts. *Plast Reconstr Surg* 1974;**54**:616.
13. Tegtmeier RE. A quick, accurate mammometer. *Ann Plast Surg* 1978;**1**:625–6.
14. Wilkie T. Volumetric breast measurement during surgery. *Aesthetic Plast Surg* 1977;**1**:301–5.
15. Campaigne BN, Katch VL, Freedson P, et al. Measurement of breast volume in females: description of a reliable method. *Ann Hum Biol* 1979;**6**:363–7.
16. Edsander-Nord A, Wickman M, Jurell G. Measurement of breast volume with thermoplastic casts. *Scand J Plast Reconstr Surg Hand Surg* 1996;**30**:129–32.
17. Neal AJ, Torr M, Helyer S, et al. Correlation of breast dose heterogeneity with breast size using 3D CT planning and dose–volume histograms. *Radiother Oncol* 1995;**34**:210–8.
18. Fowler PA, Casey CE, Cameron GG, et al. Cyclic changes in composition and volume of the breast during the menstrual cycle, measured by magnetic resonance imaging. *Br J Obstet Gynaecol* 1990;**97**:595–602.
19. Nahabedian MY, Galdino G. Symmetrical breast reconstruction: is there a role for three-dimensional digital photography? *Plast Reconstr Surg* 2003;**112**:1582–90.
20. Galdino GM, Nahabedian M, Chiaramonte M, et al. Clinical applications of three-dimensional photography in breast surgery. *Plast Reconstr Surg* 2002;**110**:58–70.
21. Kovacs L, Eder M, Papadopoulos NA, et al. Re: validating three-dimensional imaging of the breast. *Ann Plast Surg* 2005;**55**:695–6.
22. Kovacs L, Yassouridis A, Zimmermann A, et al. Optimisation of the three-dimensional imaging of the breast region with 3D Laser Scanners. *Ann Plast Surg* 2006;**56**:229–36.
23. Lee HY, Hong K, Kim EA. Measurement protocol of women's nude breasts using a 3D scanning technique. *Appl Ergon* 2004;**35**:353–9.
24. Losken A, Seify H, Denson DD, et al. Validating three-dimensional imaging of the breast. *Ann Plast Surg* 2005;**54**:471–6 (Discussion 477–478).
25. Losken A, Fishman I, Denson DD, et al. An objective evaluation of breast symmetry and shape differences using 3-dimensional images. *Ann Plast Surg* 2005;**55**:571–5.
26. Isogai N, Sai K, Kamiishi H, et al. Quantitative analysis of the reconstructed breast using a 3-dimensional laser light scanner. *Ann Plast Surg* 2006;**56**:237–42.
27. Palin Jr. WE, von Fraunhofer JA, Smith Jr. DJ. Measurement of breast volume: comparison of techniques. *Plast Reconstr Surg* 1986;**77**:253–5.
28. Kovacs L, Eder M, Hollweck R, et al. New aspects of breast volume measurement using 3D surface imaging. *Ann Plast Surg.*, 2006;57: in press.
29. Mineyev M, Kramer D, Kaufman L, et al. Measurement of breast implant volume with magnetic resonance imaging. *Ann Plast Surg* 1995;**34**:348–51.
30. Katch VL, Campaigne B, Freedson P, et al. Contribution of breast volume and weight to body fat distribution in females. *Am J Phys Anthropol* 1980;**53**:93–100.
31. Caruso MK, Guillot TS, Nguyen T, et al. The cost effectiveness of three different measures of breast volume. *Aesthetic Plast Surg* 2006;**30**:16–20.
32. Nahabedian MY. Invited discussion: validating three-dimensional imaging of the breast. *Ann Plast Surg* 2005;**54**:477–8.
33. Jacobs RA. Three-dimensional photography. *Plast Reconstr Surg* 2001;**107**:276–7.