Original Science

Surgical Innovation
20(4) 356–364

DOI: 10.1177/1553350612460127
sri.sagepub.com
SAGE

Prediction of Breast Resection Weight in Reduction Mammaplasty Based on 3-Dimensional Surface Imaging

Maximilian Eder, MD[1], Ariane Grabhorn, MD[2], Fee v. Waldenfels, MD[1], Tibor Schuster, Dipl-Stat[1], Nikolaos A. Papadopulos, PhD[1], Hans-Günther Machens, PhD[1], and Laszlo Kovacs, PhD[1]

Abstract

Prediction of resection weight (RW) in reduction mammaplasty is helpful in achieving breast symmetry and in fulfilling the stringent reimbursement requirements of health insurance companies. Current breast volume estimations are largely based on surgeon's experience, which are partially unreliable and often cumbersome to obtain. Therefore, this study aims to develop a formula to predict RW based on 3D surface imaging. A total of 68 breasts were treated with bilateral T-scar, and 40 breasts were treated with bilateral or unilateral vertical-scar reduction mammaplasty. Linear distances and volume measurements were assessed 3-dimensionally preoperatively and 6 months postoperatively. Significant correlations between the RW and the calculated preoperative breast volume ($\rho = 0.804$) and the sternal notch to nipple distance ($\rho = 0.839$) were found in both techniques ($P < .001$). Regression equations with the RW were performed to derive prediction formulas. Surgeons may benefit from the formulas in terms of improvement in preoperative planning, dealing with insurance coverage questions, and optimizing patient consultation.

Keywords

breast surgery, surgical education, surgical oncology

Introduction

It is well known that breast hypertrophy patients suffer physically and psychologically under the discomfort of their disproportionate, heavy breasts.[1-3] This aggravates the desire of these women to have reduction mammaplasty.[4] Besides the aesthetic improvement, medical benefit in terms of improvement of symptoms and health-related quality of life after breast reduction has been reported.[5-9] Nevertheless, reimbursement of the associated costs is more often restricted by the insurance companies, which commonly define reduction mammaplasty as a nonfunctional and aesthetic procedure.[10] Stringent and arbitrary insurance evaluations demanding a minimum resection weight (RW) of 350 to 500 g per side are sometimes required for coverage of the procedure.[6,11,12] In particular, breast volume estimation in mamma hypertrophy patients with large and pendulous breasts is challenging and purely intuitive.[13] Several approaches to estimate RW and breast volume have been described using water displacement,[14] anthropomorphic measurements,[15,16] casting techniques,[17] radiological measurements,[18,19] and formulas derived from regression analysis between distance measurements and bra size or resection volumes.[12,20-29] Reliable and objective breast RW determination can provide helpful preoperative and intraoperative assistance for the surgeon to achieve optimal breast cosmesis, especially in breast asymmetry or unilateral reduction in reconstructive operations, and to fulfill reimbursement requirements.[26-28] But current techniques are largely based on surgeon's experience, which are partially unreliable, often cumbersome, and not in widespread use.[28-30] Therefore, the purpose of this study was to develop a dependable formula for predicting the RW of 2 different reduction mammaplasty techniques based on 3D surface imaging, which has proved to be highly accurate and precise in breast region measurements.[30-37]

[1]Klinikum rechts der Isar, Technische Universität München, München, Germany
[2]Orthopaedic Hospital Schloss Werneck, Werneck, Germany

Corresponding Author:
Laszlo Kovacs, Department of Plastic Surgery and Hand Surgery, Klinikum rechts der Isar, Technische Universität München, Ismaninger Straße 11, D-81675 München, Germany.
Email: l.kovacs@lrz.tum.de

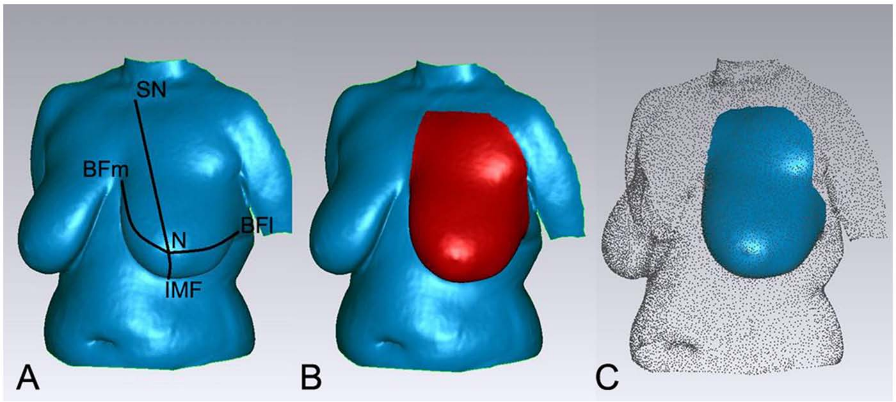

Figure 1. 3D breast measurements: A. Linear distance measurements: sternal notch to nipple (SN-N), nipple to inframammary fold (N-IMF), nipple to medial breast fold (N-BFm), nipple to lateral breast fold (N-BFl). B. Marking of the breast volume to be measured. C. Final breast volume in cubic centimeters.

Patients and Methods

Patient Enrollment

A total of 34 female patients who had obtained bilateral superior pedicled inverted T-scar reduction mammaplasty according to Höhler,[38] which is a modified Pitanguy technique, and 25 female patients who underwent bilateral or unilateral superior pedicled vertical-scar reduction according to Lejour[39] were enrolled into the study. All inverted T-scar procedures were performed by 1 single surgeon, and all the vertical-scar reductions by 2 different surgeons. Collected demographic data included age, height in centimeters, weight in kilograms, and the resulting body mass index (BMI). The RW of each breast in grams was obtained in the operating room with a calibrated scale. All patients gave their written informed consent, and the study was approved by the Ethical Committee of the Medical Faculty at the Klinikum rechts der Isar of the Technische Universität München, Germany; the Declaration of Helsinki protocols were followed.

3D Data Acquisition

A standardized 3D scanning protocol as previously reported was applied to obtain 3D breast surface imaging preoperatively and 6 months postoperatively using a Konica Minolta Vivid 910 (Konica-Minolta Co, Osaka, Japan) 3D laser scanner.[30,32-35] Under standardized lighting conditions, 3 single shots with the patient at +30°, 0°, and −30° relative to the lens were recorded and converted into 1 virtual 3D model (Figure 1) for final 3D breast measurements using specific software (Geomagic Studio 11, Raindrop Geomagic, NC).

3D Breast Measurements

Linear distance measurements (in cm; Figure 1A) were performed preoperatively and postoperatively on the virtual 3D model surfaces between specific anatomical landmarks as previously reported[35]: sternal notch to nipple (SNN), nipple to inframammary fold (NIMF), nipple to medial breast fold (NBFm), and nipple to lateral breast fold (NBFl). Preoperatively, only the NIMF distance was manually assessed with a measuring tape directly on the patient's body because in larger breasts, the inferior breast portion between the IMF and the nipple areola complex is in direct contact with the chest wall and cannot be differentiated by the 3D surface scanner.[13,33]

The breast volume to be assessed (in cc; Figures 1B and 1C) was marked on each 3D surface model at both acquisitions according to our previously described breast volume measurement protocol[30,32-34]: 1 cm beside the SN along the middle of the sternum to the BFm, caudal to the IMF up to the BFl, along the frontal axillary fold and the lateral offshoot of the pectoral muscle up to 1 cm below the clavicle, and back to the SN 1 cm caudal and parallel to the clavicle (Figure 1). The difference between preoperative and postoperative 3D breast volumes (cc) was calculated and compared with the RW (g), with an assumed mass density of 1 g/cm³ to evaluate measurement accuracy.[40]

Statistical Analysis

Mean values and standard deviations (SDs) were determined for all 3D breast measurements. To evaluate significant changes between the preoperative and postoperative 3D measurements, paired samples were analyzed using the Mann-Whitney U and Wilcoxon W tests. Relative differences between the preoperative and postoperative 3D breast volume and the RW were calculated as (Preoperative 3D volume − Postoperative 3D volume)/RW, applying the paired sample t test for control sample comparison. To investigate possible relationships among 3D breast

Table 1. Patients' Demographic Data and Preoperative and Postoperative 3D Breast Measurements.[a]

	T Scar (n = 68)		Vertical Scar (n = 40)	
	Mean	SD	Mean	SD
Demographics				
Age (years)	40.4	15.8	29.2	6.2
BMI	26.9	2.1	24.6	2.4
Resection weight (g)	614.0	152.3	232.4	93.6
Breast volume (cc)				
Preoperative	1405.6	426.7	864.4	126.0
Postoperative	792.1	295.1	632.1	91.6
Preoperative to postoperative difference	613.5	153.6	232.1	88.7
Linear measurements (cm)				
Preoperative SNN	30.4	2.5	27.4	2.6
Postoperative SNN	21.1	1.7	20.1	1.9
Preoperative NIMF	14.7	2.6	13.4	1.4
Postoperative NIMF	9.7	0.8	9.5	0.8
Preoperative NBFm	13.2	1.3	12.2	1.6
Postoperative NBFm	11.1	1.1	10.8	1.6
Preoperative NBFl	12.0	1.4	11.3	1.2
Postoperative NBFl	11.1	1.0	10.8	1.2

Abbreviations: SD, standard deviation; SNN, sternal notch to nipple; NIMF, nipple to inframammary fold; NBFm, nipple to medial breast fold: NBFl, nipple to lateral breast fold.

[a]Mean and SD are given for both surgical techniques: 34 patients (n = 68 breasts) obtained inverted T-scar reduction mammaplasty, and 25 patients (n = 40 breasts) underwent vertical-scar breast reduction. Linear distance measurements (cm) are given for SNN, NIMF, NBFm, and NBFl. Preoperative and postoperative 3D breast volume measurements and calculated differences between preoperative and postoperative 3D breast volumes (cc) are also provided.

measurements and the RW, Spearman's rank correlation coefficient (ρ) was computed and linear regression analysis performed. All tests were 2 tailed using a global significance level of $P < .05$ using SPSS version 13 (SPSS Inc, Chicago, IL) and Excel 2007 (Microsoft Office 2007, Microsoft Deutschland GmbH, Germany).

Results

Patient Data

The patient's demographic data for both surgical techniques are summarized in Table 1. All 34 female patients in the T-scar group underwent bilateral reduction mammaplasty (n = 68); in the vertical-scar group, 15 bilateral (n = 30) and 10 unilateral (n = 10) breast reductions were performed on 25 female patients. Mean age in the T-scar (vertical-scar) group was 40.4 ± 15.8 (29.2 ± 6.2) years, ranging from 18 to 61 (18-39) years, with a mean BMI of 26.9 ± 2.1 (24.6 ± 2.4) kg/m^2. The mean RW in the T-scar group was 614 ± 152.3 g (range = 402-946 g) and 232.4 ± 93.6 g in the vertical-scar group (range = 79.5-402.5 g). All T-scar group values were significantly higher compared with values for the vertical-scar group ($P = .01$-$.001$).

3D Breast Measurements

Mean preoperative and postoperative 3D breast measurement values (±SD) for both surgical techniques are shown in Table 1. All 3D breast measurement values showed relevant changes between preoperative and postoperative values ($P < .001$). For example, the mean SNN distance change in the T-scar group was 9.3 ± 2.5 cm compared with 7.3 ± 2.3 cm in the vertical-scar group. In general, linear distance changes in vertical-scar reductions are substantially smaller than in T-scar reductions ($P < .01$). All preoperative T-scar group distances compared with the vertical-scar group were decisively higher ($P = .001$) than after surgery ($P = .04$), indicating a slight but not significant postoperative breast contour alignment between the 2 techniques.

The mean preoperative T-scar breast volume was 1405.6 ± 426.7 cc (range = 875.6-2102.5 cc) and essentially higher ($P < .001$) than in the vertical-scar group with 864.4 ± 126 cc (range = 664-1114.5 cc). After surgery, the T-scar volumes were still substantially higher ($P = .02$) but comparable to the linear distance measurements; a nonsignificant postoperative alignment between the 2 techniques were seen. The mean relative difference between the preoperative to postoperative 3D breast volume (T-scar: 613.5 ± 153.6 cc; vertical-scar: 232.1 ± 88.7 cc) and the RW (T-scar: 614 ± 152.3 cc; vertical-scar: 232.4 ± 93.6 cc) was 1.0 for the T-scar and 1.02 for the vertical-scar technique. A value of 1.0 indicates perfect agreement, with 0% difference, and a value of 1.02 indicates that the 3D breast volume difference was 2% higher than the RW, without relevant differences between the 3D volumes and the RW for both techniques ($P = .910$).

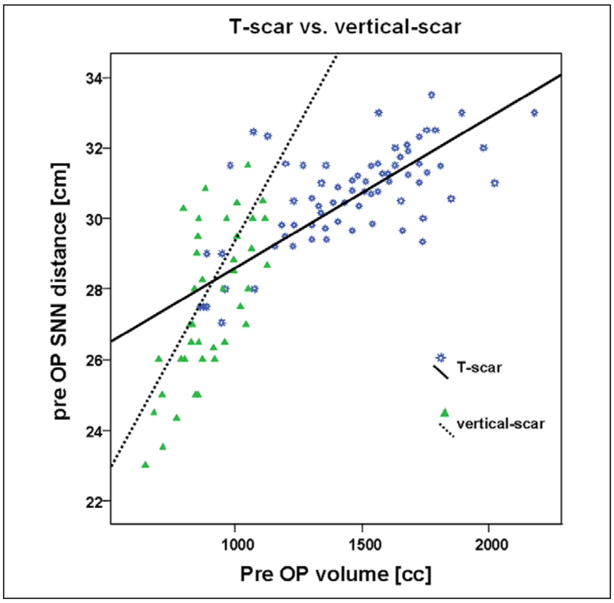

Figure 2. Correlation between the measured 3D preoperative (pre OP) volume (cc) and the sternal notch to nipple (SNN) distance (cm) for both techniques..

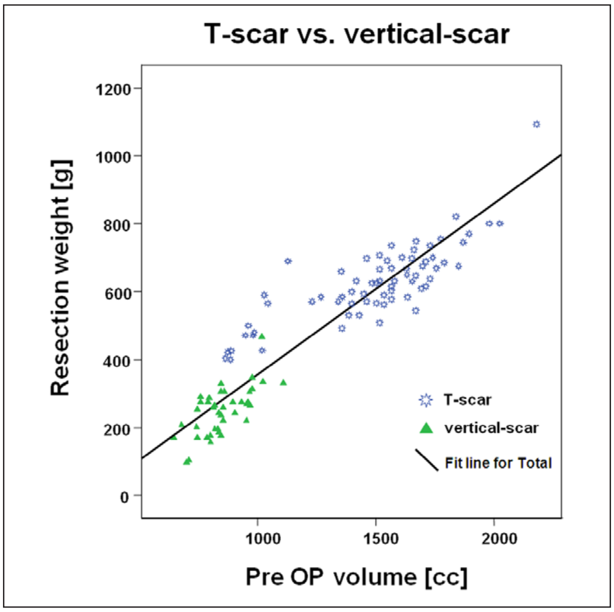

Figure 3. Correlation between the measured 3D preoperative (pre OP) volume (cc) and the resection weight (g) for both techniques.

In addition, high correlation between the preoperative to postoperative 3D breast volume difference and the RW for both techniques (T-scar: ρ = 0.993; vertical-scar: ρ = 0.978; both $P < .001$) were found (Table 1). Both values expressed the excellent 3-D measurement accuracy.

Regression Equations

Simple linear regression analysis showed no correlation between age, BMI, and 3D breast measurements or RWs. Weak to high significant correlations between the preoperative 3D breast volume and all preoperative linear distances for both surgical techniques were demonstrated: NBFm, ρ = 0.356, $P = .005$; NBFl, ρ = 0.368, $P = .004$; NIMF, ρ = 0.415, $P = .001$; SNN, ρ = 0.839, $P < .001$. This enabled the calculation of a formula to predict preoperative volume using preoperative SNN as the strongest correlated value (Figure 2):

$$\text{T-scar preoperative volume (cc)} = \text{Preoperative SNN} - (26.626/0.003), \quad (1)$$

$$\text{Vertical-scar preoperative volume (cc)} = \text{Preoperative SNN} - (19.020/0.01). \quad (2)$$

Further analysis showed a highly significant correlation (ρ = 0.804; $P < .001$) between the RW and the preoperative 3D breast volume for both surgical techniques (Figure 3), yielding the following formula to predict RW:

$$\text{T-scar RW (g)} = 156.931 + 0.325 \times \text{Preoperative volume}, \quad (3)$$

$$\text{Vertical-scar RW (g)} = -204 + 0.506 \times \text{Preoperative volume}. \quad (4)$$

Combining both equations for each surgical technique leads to the following formula for preoperative RW prediction in reduction mammaplasty (Table 2):

$$\text{T-scar RW (g)} = 156.931 + 0.325 \times (\text{Preoperative SNN} - 26.626/0.003), \quad (5)$$

$$\text{Vertical-scar RW (g)} = -204 + 0.506 \times (\text{Preoperative SNN} - 19.020/0.01). \quad (6)$$

For example, the patient in Figure 1 undergoing bilateral inverted T-scar reduction mammaplasty had a preoperative SNN distance of 30.2 cm for the left breast. The SNN value was entered into Equation 5: T-scar RW (g) = 156.931 + 0.325 × (30.2 − 26.626/0.003) = 544 g. The intraoperatively recorded actual RW for this breast was 558 g. In general, the mean predicted RW using our formula (T scar: 565 g; vertical scar: 220 g) compared with the mean actual RWs (T scar: 614 g; vertical scar: 232.4 g) showed an average relative difference of 0.92 for the T-scar approach and 0.95 for the vertical-scar approach, without relevant differences between the predicted and the actual RWs for both techniques ($P = .652$). These findings demonstrate that the RW is underestimated by 8% (49 g) in the T-scar and by 5% (12.4 g) in the vertical-scar group, using the formula we obtained.

Discussion

A number of approaches have been presented for breast volume estimations and for preoperative RW prediction

Table 2. Formulas for Preoperative vol and Breast RW Calculations Using the Preoperative SNN Distance (in cm) for Inverted T-Scar and Vertical-Scar Reduction Mammaplasty.

Value	Formula	
	T Scar	Vertical Scar
Preoperative vol (cc)	SNN − (26.626/0.003)	SNN − (19.020/0.01)
RW (g)	156.931 + 0.325 × Preoperative vol	−204 + (0.506 × Preoperative vol)
RW (g)	156.931 + 0.325 × (SNN − [26.626/0.003])	−204 + 0.506 × (Preoperative SNN − [19.020/0.01])

Abbreviations: Preoperative vol, preoperative breast volume; RW, resection weight; SNN, sternal notch to nipple distance.

in reduction mammaplasty.[12,20-34] Regnault and Daniel[20] presented a formula (later modified by Turner and Dujon[22]) to estimate the reduction in weight to achieve a desired bra size. Determination of bra size, including band size, bust circumference, and cup size, showed weak correlation with breast volume and is not applicable in breast asymmetry evaluation.[21,26-28]

Brown et al[23] developed a formula to anticipate RW before breast reduction by projecting a half-ellipsoid onto the preoperative 2D breast photography to calculate breast volume according to the geometrical parameters of the half-ellipsoid. Next, the desired postoperative breast contour was drawn in the 2D photograph by the surgeon, and the corresponding parameter changes compared with the preoperative breast contour enabled breast RW prediction using the developed formula. Our preliminary study showed that volume calculations using predefined geometrical shapes do not correspond to the individual anatomical breast conditions and result in higher measurement deviations.[30]

Formula calculations to predict breast volume or reduction weight according to regression analysis between body surface area (BSA), preoperative distance measurements, BMI, and resection volumes gained considerable attention because of user-friendly application and cost-effectiveness.[10,12,26-29]

The Schnur sliding scale correlated BSA with RW, concluding that breast reductions in the upper 78th BSA percentile were symptom related and became popular in the United States to differentiate between insurance-covered reduction and cosmetic procedures.[10] Limitations of this procedure, which is based on a single, nonaccurate parameter to predict RW, are obvious. RW correlates poorly in clinical applications with the Schnur scale, and it is not applicable for breast asymmetry assessment.[11,29,41]

Sigurdson and Kirkland[26] defined a formula for breast volume determination in patients with breast hypertrophy based on a vertical and a horizontal anthropomorphic linear distance measurement. Kocak et al[28] transferred this principle to develop a formula for breast reduction weight estimation in reduction mammaplasty. We agree that anthropomorphic measurements are relatively feasible, cheap, and quick to perform and can be accomplished with a standing patient. But our preliminary findings showed that manually performed anthropomorphic measurements are less reliable and are examiner dependent because of internal measurement variations and lack of anatomically well-defined landmarks.[13,30,35]

Sommer et al[12] correlated the preoperative SNN distance, Descamps et al[27] the preoperative SNN and preoperative NIMF distance, and Appel et al[29] the preoperative SNN distance, preoperative NIMF distance, and the BMI with the RW and developed formulas to predict breast reduction weight. In contrast to other studies claiming less accuracy applying these measurements,[26,28] our findings correspond to the results of the 3 above-named studies. Besides BMI, all preoperative 3D linear distance measurements are potential predictive parameters with variable significances for RW calculations. All studies reported high correlation between the predicted and actual RWs, but unfortunately, no accuracy studies were performed to show the measurement uncertainty that surgeons have to deal with intraoperatively.[27-29]

The study by Losken et al[31] and our preliminary studies[30,32-34] demonstrated the high accuracy and precision of 3D surface imaging in linear distance measurements and breast volume calculations for clinical applications correlating with MRI measurements and implant and resection volumes in breast surgery. The presented mean breast volume measurement accuracy of between 0% and 2% correspond with those in previous studies[31,32] and confirmed our findings that the most precise breast volume measurements are performed between 300 and 1600 cc, depending on the relevant anatomical influences previously described by us.[32,34] The presented decreased accuracy for RW prediction of between 5% and 8% using the formula obtained is, in our opinion, mainly caused by the wide range of assessed breast volumes (range = 664-2102.5 cc), with preoperative volumes larger than 1600 cc in 12% of the patients. On the other hand, we believe that absolute volume differences of between 12 and 50 g compared with the actual RW are of minor clinical relevance.

3D surface imaging provides accurate and precise breast measurements, and data acquisition and evaluation take approximately 10 to 12 minutes in experienced hands, but the existing hardware and software are not affordable to everybody, although costs have decreased

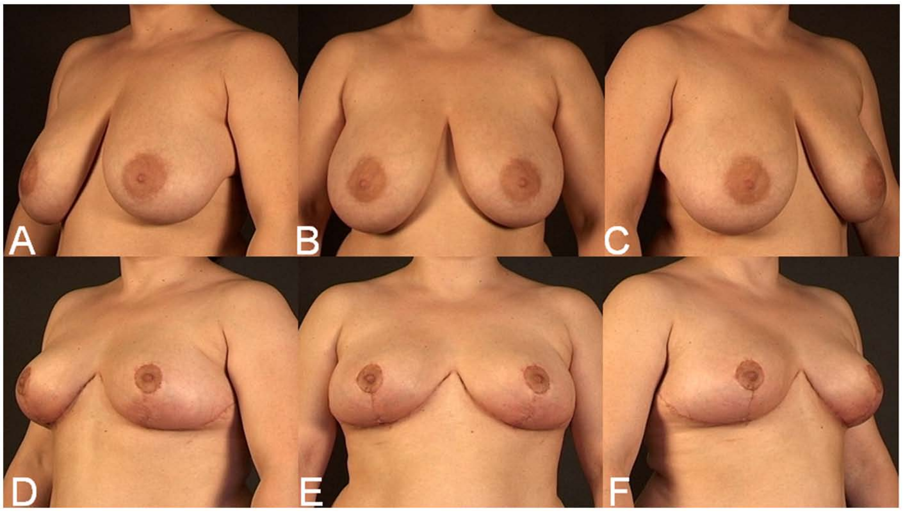

Figure 4. A 32-year-old female patient with bilateral breast hyperplasia and existing mild breast asymmetry (A-C preoperative views) underwent bilateral inverted T-scar reduction mammaplasty (D-F postoperative views). The preoperative SNN distance of 28.8 cm on the right breast predicted a RW of 392 g and the preoperative SNN distance of 28.2 cm on the left breast predicted a RW of 327 g using the formula for T-scar reduction in Table 2; actual RW was 415 g on the right and 350 g on the left side
Abbreviations: SNN, sternal notch to nipple; RW, resection weight.

in recent years, and complete solutions are available from around 35 000 US dollars.[42] Therefore, our main objective was to develop a formula that can be applied by everyone, manually measuring 1 linear distance preoperatively and computing the RW using a formula based on an accurate and highly correlated 3D measurement technique. Although our previous findings imply that anthropomorphic measurements are less reliable and are examiner dependent,[13,30,35] the presented study revealed acceptable correlation for RW prediction using linear distance measurements. Because of the above-named shortcomings and the knowledge that manual measurements between the well-defined SN and the clearly definable nipple are more accurate than measurements between the nipple and the often arbitrary definable inframammary fold, especially in breast hypertrophy, we only integrated the highest significant value (preoperative SNN) into the formula.[13,35]

Currently, 3D surface imaging is not applied in clinical routine because of the above-mentioned disadvantages. Therefore, we believe that the present method using anthropomorphic correlations will be highly appreciated because of its feasibility, user-friendly nature, and cost-effectiveness. The existing limitations of the presented study (different surgeons, sample size, and only superior pedicled reduction techniques) underline the need for future long-term studies. Currently, the proposed method works for the T-scar technique with preoperative breast volumes ranging from 875.6 to 2102.5 cc and for the vertical-scar group with preoperative breast volumes ranging from 664 to 1114.5 cc. But further studies are needed to analyze the reliability of the presented formulas in reduction mammaplasty patients with varying breast shapes and sizes—for example very ptotic breasts and larger SNN distances. Furthermore, the potential influence of the developed formulas to improve the surgical learning curve of younger surgeons has to be critically analyzed in the future. It would be of great interest to apply the existing formulas on a larger population, to get the method validated by other surgeons regarding measurement accuracy, and to enlarge our methodology to other surgical breast reduction techniques in the future.[43]

Conclusions

In conclusion, breast RW for 2 different surgical approaches can be accurately predicted by our formula based on 3D breast measurements (Table 2). This method can be used by breast surgeons to deal with debatable insurance coverage questions and to make patient consultation and communication more transparent. In addition, the clinical relevance of this formula may help surgeons in breast reduction planning by calculating the preoperative

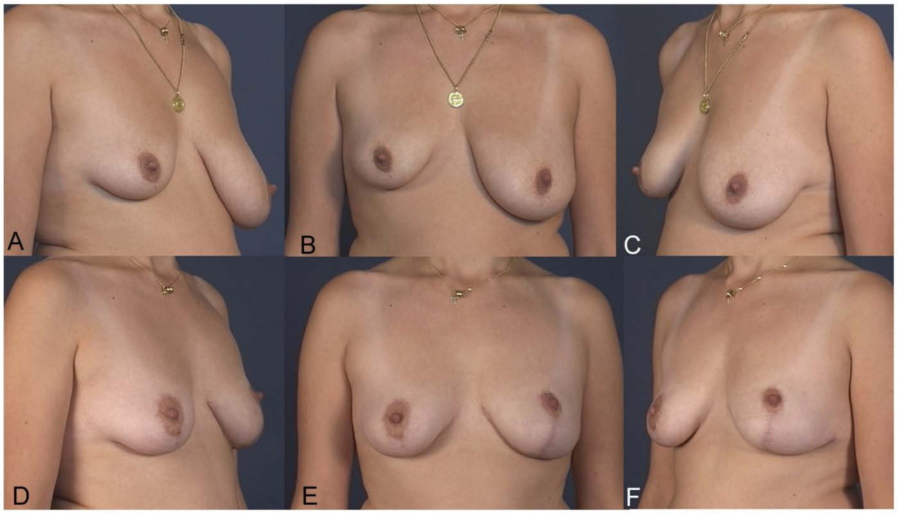

Figure 5. A 29-year-old female patient with congenital unilateral left breast hyperplasia (A-C preoperative views) underwent vertical-scar reduction mammaplasty of the malformed left breast to correct breast asymmetry (D-F postoperative views). The preoperative SNN distance of 27.3 cm predicted a RW of 215 g using the formula for vertical-scar reduction in Table 2; actual RW: 223 g.
Abbreviations: SNN, sternal notch to nipple; RW, resection weight.

breast volume and the desired RW (Figure 4); it can especially be used as an intraoperative guide in existing breast asymmetry (Figure 5) or unilateral breast reconstruction to obtain optimal cosmesis.

Acknowledgments

The authors would like to thank Prof. Dr. rer.-nat. A. Haase, Director of the Zentralinstitut für Medizintechnik (IMETUM), Technische Universität München, Germany, for his cooperation and infrastructural support. Furthermore, the authors thank Prof. Dr. D. Liebermann-Meffert, Department of Surgery, Klinikum rechts der Isar, Technische Universität München, Germany, for reviewing the article and for her constructive commentaries. In addition, we would like to thank all the medical staff of the Department of Plastic Surgery and Hand Surgery, Klinikum rechts der Isar, Technische Universität München, Germany, who were involved in the surgical treatment of the patients included in the study.

Authors' Note

The authors do not have any financial interests and personal relationships with other people or organizations that inappropriately influence (bias) their work. None of the authors is a shareholder of any of the named companies whose hardware (Konica Minolta Co, Osaka, Japan) or software (Raindrop Geomagic, NC) was used in the study, and no author has any other financial interests with the named companies. Part of this work was presented at the 53rd Annual Meeting of the Plastic Surgery Research Council in Springfield, IL, USA, held between June 28 and June 31, 2008.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article:

Funding for the study was received by the Federal Ministry of Economics and Technology, Germany (BMWi-Funding No.: 16INO607).

References

1. Blomqvist L, Eriksson A, Brandberg Y. Reduction mammaplasty provides long-term improvement in health status and quality of life. *Plast Reconstr Surg*. 2000;106:991-997.
2. Schnur PL, Schnur DP, Petty PM, et al. Reduction mammaplasty: an outcome study. *Plast Reconstr Surg*. 1997;100:875-883.
3. Faria FS, Guthrie E, Bradbury E, et al. Psychosocial outcome and patient satisfaction following breast reduction surgery. *Br J Plast Surg.* 1999;52:448-452.
4. Birtchnell S, Whitfield P, Lacey JH. Motivational factors in women requesting augmentation and reduction mammaplasty. *J Psychosom Res*. 1990;34:509-514.

5. Blomqvist L, Brandberg Y. Three-year follow-up on clinical symptoms and health-related quality of life after reduction mammaplasty. *Plast Reconstr Surg*. 2004;114:49-54.
6. Chao JD, Memmel HC, Redding JF, et al. Reduction mammaplasty is a functional operation, improving quality of life in symptomatic women: a prospective, single-center breast reduction outcome study. *Plast Reconstr Surg*. 2002;110:1644-1652; discussion 1653-1654.
7. Glatt BS, Sarwer DB, O'Hara DE, et al. A retrospective study of changes in physical symptoms and body image after reduction mammaplasty. *Plast Reconstr Surg.* 1999;103:76-82; discussion 83-85.
8. Thoma A, Sprague S, Veltri K, et al. A prospective study of patients undergoing breast reduction surgery: health-related quality of life and clinical outcomes. *Plast Reconstr Surg*. 2007;120:13-26.
9. Spector JA, Karp NS. Reduction mammaplasty: a significant improvement at any size. *Plast Reconstr Surg.* 2007;120:845-850.
10. Schnur PL, Hoehn JG, Ilstrup DM, et al. Reduction mammaplasty: cosmetic or reconstructive procedure? *Ann Plast Surg.* 1991;27:232-237.
11. Seitchik MW. Reduction mammaplasty: criteria for insurance coverage. *Plast Reconstr Surg.* 1995;95:1029-1032.
12. Sommer NZ, Zook EG, Verhulst SJ. The prediction of breast reduction weight. *Plast Reconstr Surg.* 2002;109:506-511.
13. Eder M, Papadopulos NA, Kovacs L. Breast volume determination in breast hypertrophy. *Plast Reconstr Surg.* 2007;120:356-357.
14. Schultz RC, Dolezal RF, Nolan J. Further applications of Archimedes' principle in the correction of asymmetrical breasts. *Ann Plast Surg.* 1986;16:98-101.
15. Penn J. Breast reduction. *Br J Plast Surg.* 1955;7:357-371.
16. Smith DJ Jr, Palin WE Jr, Katch VL, et al. Breast volume and anthropomorphic measurements: normal values. *Plast Reconstr Surg.* 1986;78:331-335.
17. Ingleby H. Changes in breast volume in a group of normal young women. *Bull Int Assoc Med Mus.* 1949;29:87-92.
18. Kalbhen CL, McGill JJ, Fendley PM, et al. Mammographic determination of breast volume: comparing different methods. *Am J Roentgenol.* 1999;173:1643-1649.
19. Pozzobon AV, Sabino Neto M, Veiga DF, et al. Magnetic resonance images and linear measurements in the surgical treatment of breast asymmetry. *Aesthetic Plast Surg.* 2009;33:196-203.
20. Regnault P, Daniel RK. Breast reduction. In: Regnault P, Daniel RK, eds. *Aesthetic Plastic Surgery: Principles and Techniques*. Boston, MA: Little Brown; 1984:499-538.
21. Pechter EA. A new method for determining bra size and predicting postaugmentation breast size. *Plast Reconstr Surg*. 1998;102:1259-1265.
22. Turner AJ, Dujon DG. Predicting cup size after reduction mammaplasty. *Br J Plast Surg*. 2005;58:290-298.
23. Brown RW, Cheng YC, Kurtay M, et al. A formula for surgical modifications of the breast. *Plast Reconstr Surg.* 2000;106:1342-1345.
24. Qiao Q, Zhou G, Ling Y. Breast volume measurement in young Chinese women and clinical applications. *Aesthetic Plast Surg.* 1997;21:362-368.
25. Westreich M. Anthropomorphic breast measurement: protocol and results in 50 women with aesthetically perfect breasts and clinical application. *Plast Reconstr Surg.* 1997;100:468-479.
26. Sigurdson LJ, Kirkland SA. Breast volume determination in breast hypertrophy: an accurate method using two anthropomorphic measurements. *Plast Reconstr Surg.* 2006;118:313-3120.
27. Descamps MJ, Landau AG, Lazarus D, et al. A formula determining resection weights for reduction mammaplasty. *Plast Reconstr Surg.* 2008;121:397-400.
28. Kocak E, Carruthers KH, McMahan JD. A reliable method for the preoperative estimation of tissue to be removed during reduction mammaplasty. *Plast Reconstr Surg.* 2011;127:1059-1064.
29. Appel JZ III, Wendel JJ, Zellner EG, et al. Association between preoperative measurements and resection weight in patients undergoing reduction mammaplasty. *Ann Plast Surg.* 2010;64:512-515.
30. Kovacs L, Eder M, Hollweck R, et al. Comparison between breast volume measurement using 3D surface imaging and classical techniques. *Breast.* 2007;16:137-145.
31. Losken A, Seify H, Denson DD, et al. Validating three-dimensional imaging of the breast. *Ann Plast Surg.* 2005;54:471-476; discussion 477-478.
32. Kovacs L, Eder M, Hollweck R, et al. New aspects of breast volume measurement using 3-dimensional surface imaging. *Ann Plast Surg.* 2006;57:602-610.
33. Eder M, Papadopulos NA, Machens HG, et al. Three-dimensional surface imaging for objective quantification and prediction of breast reduction mammaplasty: gain or gadget? *Plast Reconstr Surg*. 2008;121(6S):71.
34. Eder M, Schneider A, Feussner H, et al. Breast volume assessment based on 3D surface geometry: verification of the method using MR imaging. *Biomed Tech (Berl)*. 2008;53:112-121.
35. Kovacs L, Yassouridis A, Zimmermann A, et al. Optimization of 3-dimensional imaging of the breast region with 3-dimensional laser scanners. *Ann Plast Surg.* 2006;56:229-236.
36. Eder M, Kovacs L. Commentary on the article of Herold et al.: The use of mamma MRI volumetry to evaluate the rates of fat survival after autologous lipotransfer. *Handchir Mikrochir Plast Chir.* 2010;42:135-136.
37. Eder M, Papadopulos NA, Kovacs L. Re: Virtual 3-dimensional modeling as a valuable adjunct to aesthetic and reconstructive breast surgery. *Am J Surg.* 2007;194:563-565.

38. Höhler H. Reduction mammoplasty in hyperplasias of the female breast. *Chirurg.* 1977;48:377-383.
39. Lejour M. Vertical mammaplasty. *Plast Reconstr Surg.* 1993;92:985-986.
40. 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.
41. Nguyen JT, Wheatley MJ, Schnur PL, et al. Reduction mammaplasty: a review of managed care medical policy coverage criteria. *Plast Reconstr Surg.* 2008;121:1092-1100.
42. Tepper OM, Choi M, Small K, et al. An innovative three-dimensional approach to defining the anatomical changes occurring after short scar-medial pedicle reduction mammaplasty. *Plast Reconstr Surg.* 2008;121:1875-1885.
43. Small KH, Tepper OM, Unger JG, et al. Re-defining pseudoptosis from a 3D perspective after short scar-medial pedicle reduction mammaplasty. *J Plast Reconstr Aesthet Surg.* 2010;63:346-353.