DIEP Flap Breast Reconstruction Using 3-dimensional Surface Imaging and a Printed Mold

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Summary: Recent advances in 3-dimensional (3D) surface imaging technologies allow for digital quantification of complex breast tissue. We performed 11 unilateral breast reconstructions with deep inferior epigastric artery perforator (DIEP) flaps (5 immediate, 6 delayed) using 3D surface imaging for easier surgery planning and 3D-printed molds for shaping the breast neoparenchyma. A single- or double-pedicle flap was preoperatively planned according to the estimated tissue volume required and estimated total flap volume. The DIEP flap was then intraoperatively shaped with a 3D-printed mold that was based on a horizontally inverted shape of the contralateral breast. Cosmetic outcomes were assessed as satisfactory, as confirmed by the postoperative 3D measurements of bilateral breasts. We believe that DIEP flap reconstruction assisted with 3D surface imaging and a 3D-printed mold is a simple and quick method for rebuilding a symmetric breast. *(Plast Reconstr Surg Glob Open 2015;3:e316; doi: 10.1097/GOX.0000000000000288; Published online 5 March 2015)*

The deep inferior epigastric artery perforator (DIEP) flap is widely used in autologous tissue breast reconstruction because it offers a large volume of soft tissue without sacrificing the rectus muscle, with fewer complications such as hernia or bulge formation.[1,2] To optimize cosmetic outcomes in unilateral DIEP flap breast reconstruction, an adequate volume of flap tissue with good blood flow should be prepared and molded into a shape similar to the contralateral breast. For an inexperienced surgeon, however, surgery planning (eg, single- or double-pedicle) and intraoperative breast shaping can be difficult.

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Recent advances in 3-dimensional (3D) body surface imaging enable us to digitally quantify complex breast regions noninvasively.[3,4] Models built with a personal 3D printer have also been used to aid various reconstructive surgeries.[5,6] We recently used these technologies, and in this report, we document our experiences with unilateral DIEP flap breast reconstruction with 3D surface imaging to improve surgery planning and 3D-printed molds to shape a breast symmetrical to the contralateral breast.

PATIENTS AND METHODS

Between April and October 2014, unilateral breast reconstruction with a DIEP flap was performed in 11 breast cancer patients at the Osaka University Hospital. The mean age of the patients was 50.7 years (range, 41–63 years), and the mean follow-up was 5 months (range, 3–8 months). Four cases were immediate reconstructions (after skin-sparing mastectomy), 1 was a delayed-immediate reconstruction, and 6 were 2-stage delayed reconstructions. This study

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was approved by our institutional review board, and appropriate informed consent was obtained from the patients.

3D Measurement of Breast Region and Estimation of Required Flap Volume

3D surface imaging of the bilateral breast region was performed in a sitting position with the David Structured Light Scanner SLS-1 (David Vision Systems GmbH, Koblenz, Germany) according to manufacturer's instructions. Typically, 2 prepared single shots were combined into one 3D image. Analysis was then performed with 3D image data analysis software developed for breast reconstruction (Breast-Rugle, Medic Engineering, Kyoto, Japan), and breast volume was estimated bilaterally (Fig. 1A). Estimated required flap volume was based on contralateral breast volume for 1-stage reconstruction or the volume difference between both sides for 2-stage reconstruction.

In 2-stage reconstruction, an anatomical integrated port tissue expander (Natrelle133, Allergan, Tokyo, Japan) was inserted subcutaneously in patients with no radiotherapy history or subpectorally in patients with radiotherapy before reconstruction. Final expansion volume was determined by estimated required flap volume and shape of the contralateral breast.

Estimation of Total Flap Volume and Determination of Flap Type

The total volume of DIEP flap can be precisely estimated by abdominal multidetector-row computed tomography and 3D imaging software.[7] However, total flap volume can also be estimated with the following formula: total flap volume (ml) = total flap area (cm^2) × mean subcutaneous fat thickness (cm). Total flap area was calculated using a preoperative abdominal photograph (Fig. 1B) and public domain image software (Image J, Wayne Rasband, National Institute of Health, Bethesda, Md.)). Mean subcutaneous fat thickness was determined by ultrasonic evaluation of subcutaneous fat at the upper and lower borders of the flap (Fig. 1B). Flap type was determined by dividing required flap volume by total flap volume, with a value greater than 0.6–0.7 (depending on size, number, and location of perforators[8,9]) necessitating a double-pedicle DIEP flap (ie, bilateral deep inferior epigastric vessels are used) (Fig. 1C).

Breast Mold Creation and Breast Mound Shaping

Using the Breast-Rugle software, contralateral breast data were horizontally inverted to generate breast mold data. An acrylonitrile–butadiene–styrene copolymer breast mold was then created with a personal 3D printer (MakerBot Replicator 2x, MakerBot

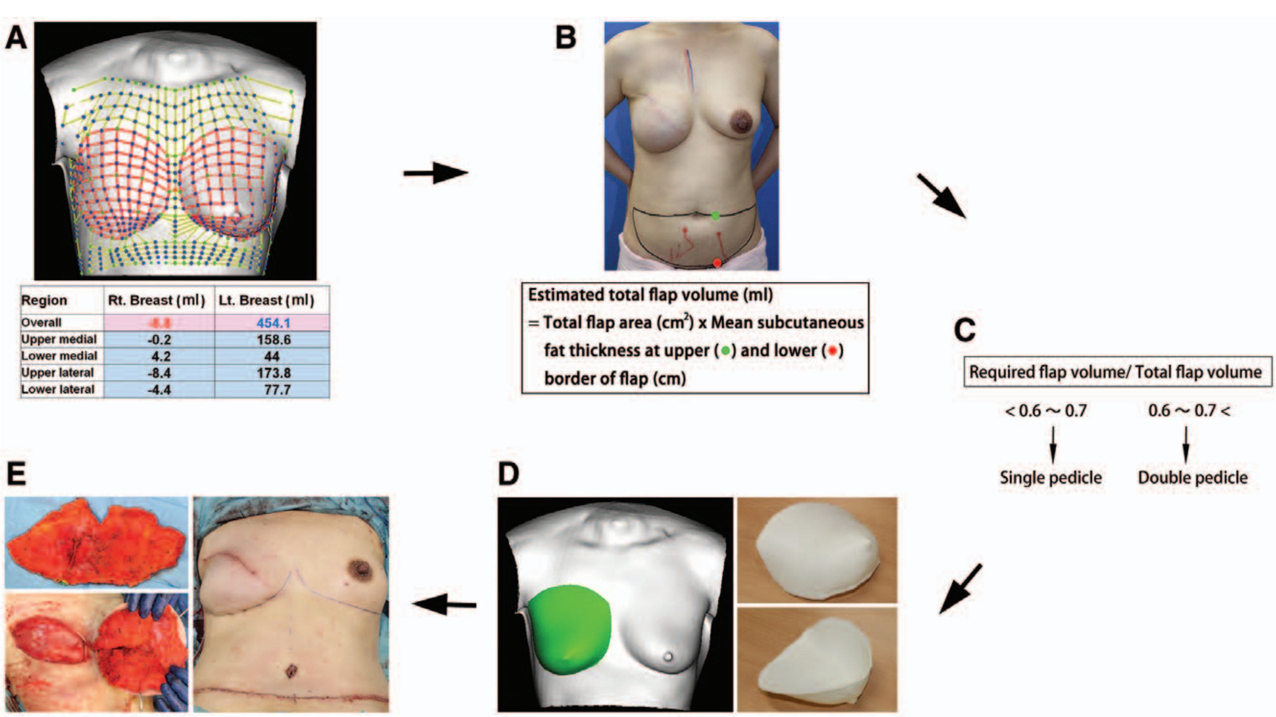

Fig. 1. Workflow images of DIEP flap breast reconstruction assisted with 3D surface imaging. A, Required flap volume was estimated from bilateral breast images using 3D image data analysis software. B and C, Total flap volume was estimated using the formula shown, and flap type was determined preoperatively. D, Contralateral breast shape was horizontally inverted, and an acrylonitrile–butadiene–styrene copolymer breast mold was created using a personal 3D printer. E, After vascular anastomosis, the de-epithelialized flap was placed in the mold and fixed to shape a symmetric breast.

Table 1. Patient Characteristics and Operative Results

Patient	Age (y)	Type of Reconstruction	Radiation History	Estimated, Required Tissue Volume (ml)	Estimated Total Flap Volume (ml)	Type of Flap	Final TE Volume (ml)	Final Flap Weight (g)	Total Flap Weight (g)	Complications	Cosmetic Results	Volume Difference (ml)*
1	58	Immediate	No	487	1088	Single pedicle	NA	526	999	No	Good	+43
2	53	Immediate	No	394	442	Double pedicle	NA	350	455	No	Excellent	+1
3	46	Immediate	No	789	1340	Single pedicle	NA	886	1583	Yes (partial necrosis)	Good	+64
4	50	Immediate	No	889	972	Double pedicle	NA	816	875	No	Excellent	+36
5	46	Delayed-immediate	No	531	592	Double pedicle	500	538	655	No	Excellent	−28
6	56	2-Stage, delayed	No	197	510	Single pedicle	300	228	467	No	Excellent	+20
7	50	2-Stage, delayed	Yes	632	1596	Single pedicle	800	747	1512	No	Fair	−86
8	63	2-Stage, delayed	No	778	1330	Double pedicle	850	866	1285	No	Good	−48
9	44	2-Stage, delayed	Yes	188	346	Single pedicle	250	175	336	No	Excellent	−5
10	51	2-Stage, delayed	No	463	604	Double pedicle	475	508	542	No	Excellent	+19
11	41	2-Stage, delayed	No	432	608	Double pedicle	525	438	550	No	Excellent	+28

*Postoperative volume difference was calculated as the reconstructed breast volume minus the contralateral breast volume.
NA, not applicable; TE, tissue expander.

Industries, Brooklyn, N.Y.), and the mold was sterilized with ethylene oxide gas for intraoperative use (Fig. 1D).

After flap elevation, total flap weight was measured and the excess portion trimmed according to the estimated required flap volume. For convenience, volume (ml) was considered equal to weight (g).[10] With the double-pedicle flap, intraflap pedicle-to-pedicle anastomosis was also performed. When vascular anastomosis and de-epithelialization were completed, the flap was carefully placed into the mold (Fig. 1E). After determination of optimal positioning and additional trimming, the flap was fixed and shaped with absorbable sutures from the bottom.

Postoperative Evaluation

Cosmetic outcomes were evaluated on a 4-point visual analogue scale as previously described.[11] Two health professionals assessed cosmetic outcomes as excellent, good, fair, or poor. 3D measurements of bilateral breasts were performed at 2 months postoperatively, and volume difference between the reconstructed and contralateral sides was assessed.

We state that all procedures conformed to the Declaration of Helsinki, and appropriate informed consent was obtained from the patients.

RESULTS

Patient characteristics and outcomes are shown in Table 1. Five flaps were single-pedicle and 6 were double-pedicle. Correlation between estimated total flap volume (ml) and actual total flap weight (g) was excellent ($r^2 = 0.95$; $m = 0.99$). The value of final flap weight tended to be slightly larger than the value of estimated required flap volume in anticipation of postoperative shrinkage.[12,13]

There was no flap loss or other major complication during the follow-up period, except for partial fat necrosis in 1 single-pedicle flap. Cosmetic outcomes were satisfactory (excellent, 7 cases; good, 3 cases; and fair, 1 case), as confirmed by the postoperative 3D measurements of the volume difference between the reconstructed and contralateral sides (mean volume difference, 34.4 ml; range, 1–86 ml). Sufficient volume replacement with DIEP flap resulted in good breast projection and symmetry for most cases (Figs. 2, 3).

DISCUSSION

Reconstructed breast shape is mainly affected by neoparenchyma and skin envelope.[14] Although DIEP flaps offer a sufficient amount of tissue as neoparenchyma, determining the optimal amount requires skill and experience. We believe 3D surface imaging offers stable estimates of required tissue volume, as evidenced by satisfactory cosmetic outcomes

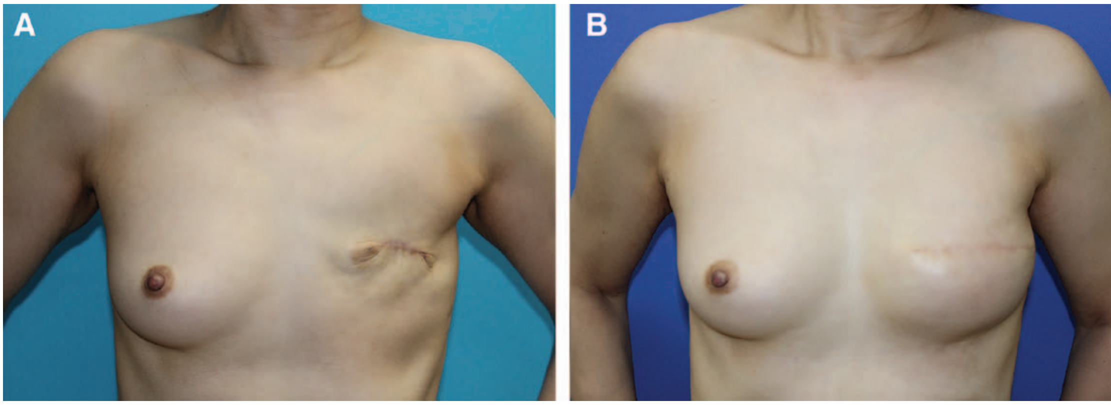

Fig. 2. A 56-year-old woman (patient 6) underwent total mastectomy of the left breast. One year later, she underwent 2-stage delayed reconstruction with a DIEP flap. The preoperative (A) and 4-month postoperative (B) views are shown.

and postoperative 3D measurements. 3D surface imaging also aids in surgery planning, especially when a large volume of tissue is required to reconstruct a symmetrical breast. Without the estimation of total flap volume and required tissue volume, flap type (single- or double-pedicle) is merely subjectively determined using fluorescent perfusion techniques. In such situations, underestimation of required tissue volume would result in insufficient breast volume, especially in a single-pedicle flap. A preoperative decision on flap type based on the objective data can make surgery more circumspect and accurate.

Shaping flat adipocutaneous tissue into a 3D structure can be challenging,[15] especially in cases where a high-profile breast must be shaped from an entire, thin DIEP flap (eg, patients 4, 5, 10, and 11). We found the 3D-printed breast mold to be a simple, quick, and inexpensive solution. Owing to its flexible nature, the de-epithelialized DIEP flap placed in a breast mold automatically changes into a shape symmetrical to the contralateral breast and only needs minor adjustments. Material costs were less than 5 dollars per mold.

There are potential drawbacks to this method. Because 3D surface imaging does not take skin envelope thickness into account, and chest wall shape is estimated by 3D analysis software, there could be errors between the estimated and real tissue volume required. In immediate reconstruction, however, the errors can be corrected by intraoperative measurement of real tissue volume (or weight) resected. We found the errors to be within an allowable range for preoperative determination of flap type. Because the previously mentioned errors are offset during calculation of the breast volume difference between both sides, estimation of required tissue volume in delayed reconstruction was more accurate than in immediate reconstruction.

Because our breast mold is created based on the 3D surface imaging, and a DIEP flap is inserted into the subcutaneous pocket, the reconstructed breast is likely to be slightly larger than the contralateral breast (due to skin envelope thickness). We consider it convenient for obtaining a symmetric breast because some postoperative reduction usually occurs (5–10%) as swelling disappears.[12,13] However, when

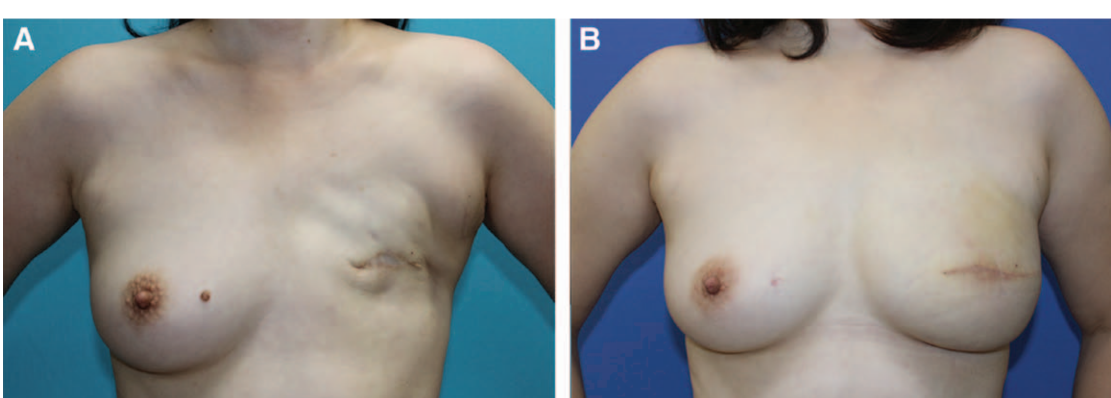

Fig. 3. A 41-year-old woman (patient 11) underwent total mastectomy of the left breast. Three years later, she underwent 2-stage delayed reconstruction with a DIEP flap. The preoperative (A) and 3-month postoperative (B) views are shown.

the breast skin is reconstructed with a flap, it would be difficult to oversize the reconstructed breast in a balanced manner.[16]

CONCLUSIONS

In conclusion, the 3D imaging technologies allow for digital quantification of complex breast tissue and circumspect preoperative planning. We believe that DIEP flap reconstruction assisted with 3D surface imaging and a 3D-printed mold is a simple and quick method to rebuild a symmetric breast even for less experienced surgeons.

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