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CLINICAL ARTICLE

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Estimation of DIEP flap weight for breast reconstruction by the pinch test

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Abstract

Background: Various methods have been introduced for estimating deep inferior epigastric artery perforator (DIEP) flap volume based on computed tomography or magnetic resonance angiographic images. However, when radiologic images cannot be obtained, estimations are subjective. The purpose of this study was to develop a prediction model for estimating DIEP flap weight using the pinch test.

Methods: The pinch test was performed at three paraumbilical sites using a skin-fold caliper in 107 consecutive patients who underwent DIEP flap breast reconstruction. Multiple linear regression analysis was used to develop a formula to estimate flap weight. Predictor variables included body mass index (BMI, kg/m^2), flap height (*H*, cm), flap width (*W*, cm), and flap thickness (mm) measured by the pinch test at the following three paraumbilical sites: 5 cm right (*R*), left (*L*), and inferior (*I*) of the umbilicus. The model accuracy was tested using leave-one-out cross-validation.

Results: A prediction model was developed from the multiple regression analysis ($R^2 = 89.03\%$, $P < .001$); flap weight, $g = -1308 + 24.57 \times \text{BMI} + 6.80 \times (R + L)/2 + 7.89 \times I + 20.51 \times H + 32.55 \times W$. The formula was implemented in a smartphone application, DIEP-W version 2.0, for real-time use. The mean absolute percentage error in the cross-validation was 12.15%.

Conclusions: DIEP flap weight can be estimated by the pinch test with the developed prediction model in an easy, cost-effective, and relatively accurate manner. This method will improve surgical planning and allow surgeons to provide better counselling for patients when radiologic images are not available.

1 | INTRODUCTION

The deep inferior epigastric artery perforator (DIEP) flap technique has become a gold standard for breast reconstruction using autologous tissue. Surgical planning of DIEP flap based on preoperative estimation of the volume of the abdominal flap has been shown to reduce perfusion-related complications (Lee & Mun, 2016) and donor site complications by avoiding elevation of excessively large flaps (Woo, Kim, Lee, & Mun, 2016). Various methods have been developed for estimating DIEP flap volume based on CT angiography or MR angiography (Eder et al., 2014; Kim et al., 2012, 2015; Nanidis, Ridha, & Jallali, 2014; Rosson et al., 2011; Sotsuka, Fujikawa, & Izumi, 2012; Tomita, Yano, Hata, Nishibayashi, & Hosokawa, 2015). When radiologic images are not available, however, these estimation methods cannot be used. Accurate estimation of the volume of the abdominal flap is crucial in patient selection, especially for patients with a mild to moderately protruded abdomen. However, no objective method has been developed for estimating the abdominal flap volume without using radiologic images. Experienced surgeons can estimate the volume by the pinch test, but this estimation relies on subjective prediction, and inexperienced surgeons tend to underestimate the available volume (Nanidis et al., 2014).

We previously demonstrated that DIEP flap weight can be estimated using paraumbilical flap thicknesses determined using CT angiographic images (Woo et al., 2016). We therefore hypothesized that DIEP flap weight could be estimated after performing the pinch test on the abdominal flap. The purposes of this study were (1) to investigate whether DIEP flap weight can be estimated by the pinch test and (2) to develop a prediction model to estimate DIEP flap weight.

2 | PATIENTS AND METHODS

A total of 107 consecutive patients who underwent DIEP flap breast reconstruction by a single senior surgeon (GH.M.) between February 2015 and November 2016 were included in this study. No patient in this study underwent muscle-sparing transverse rectus abdominis myocutaneous (TRAM) flap. Patients with vertical midline scar which can influence the pinch test were excluded from the study. Data for the potential predictive variables [body mass index (BMI, kg/m^2), flap height (H, cm), flap width (W, cm), and pinch test (mm)] were collected prospectively. Measurements were performed while the patient was lying on a bed. The pinch test was performed at three paraumbilical sites: 5 cm right (R), left (L), and inferior (I) of the umbilicus. We used a skin fold caliper (Slim Guide Caliper, Healthcheck Systems Inc., NY) with a jaw pressure that automatically adjusts to 10 g/mm^2. The full thickness of the abdominal flap was grasped using both hands, after which the caliper was applied with one hand while the other hand held the skin folds so as not to exert counter-pressure on the caliper (Supporting Information Video 1). This measurement was divided by 2 as the abdominal flap was folded onto itself during the measurement. One of the three observers repeated the measurement two times, and the mean value was used. A vertical skin fold was created to measure I, while a transverse skin fold was used to measure R and L, ensuring that the measurements were made 5 cm from the umbilicus (Figure 1). The design of the DIEP flap was a standard ellipse, as described previously (Woo et al., 2016).

For comparison, we prospectively estimated the DIEP flap volume using the CT volumetry method as described previously (Kim et al., 2012). Briefly, the abdominal flap area was defined on cross-sectional CT angiographic images. The volume was estimated by integrating each polygonal area (estimated automatically with an image-editing tool) and multiplying the result by the appropriate slice thickness (2.5 or 2.0 mm). The DIEP flap weight was also estimated using the formula DIEP-W: CT, which uses paraumbilical flap thicknesses measured on CT angiographic cross-sectional images, as previously described (Woo et al., 2016). The estimated flap weights of the two methods were compared with the intraoperative flap weight measurements in 107 consecutive patients. After the prediction model using the pinch test (hereafter referred to as the DIEP-W: Pinch method) was developed, the accuracy was compared with those of CT volumetry and DIEP-W: CT methods.

2.1 | Statistical Analysis

Correlations of paraumbilical flap thicknesses on CT angiographic images with those of the pinch test were analyzed using Pearson's correlation analysis. Multiple linear regression analysis using the Akaike information criterion (AIC) method for variable selection was performed to develop a formula to estimate the flap weight. Accuracy of the developed prediction formula was assessed using leave-one-out cross-validation. One case was selected as the validation set, and the remaining cases served as the training set; this process was repeated 107 times. Estimation of the flap weight was simulated using the developed formula in the 107 patients. To compare estimation outcomes of the developed formula with those of other methods using CT angiographic images (CT Volumetry and DIEP-W: CT methods), the mean absolute percentage errors (MAPEs) and mean absolute error values were calculated for the 107 patients. The MAPEs of the three raters were compared using Kruskal–Wallis test. The ratios of pinch thickness to CT thickness at the three paraumbilical sites of each patient were compared using an ANOVA with repeated measures with a Greenhouse–Geisser correction to evaluate intrarater reliability of the pinch measurement. A P value $<.05$ was considered to be statistically significant. Statistical analyses were performed with SAS version 9.4 (SAS Institute, Cary, NC) and R 3.2.3 (R Development Core Team).

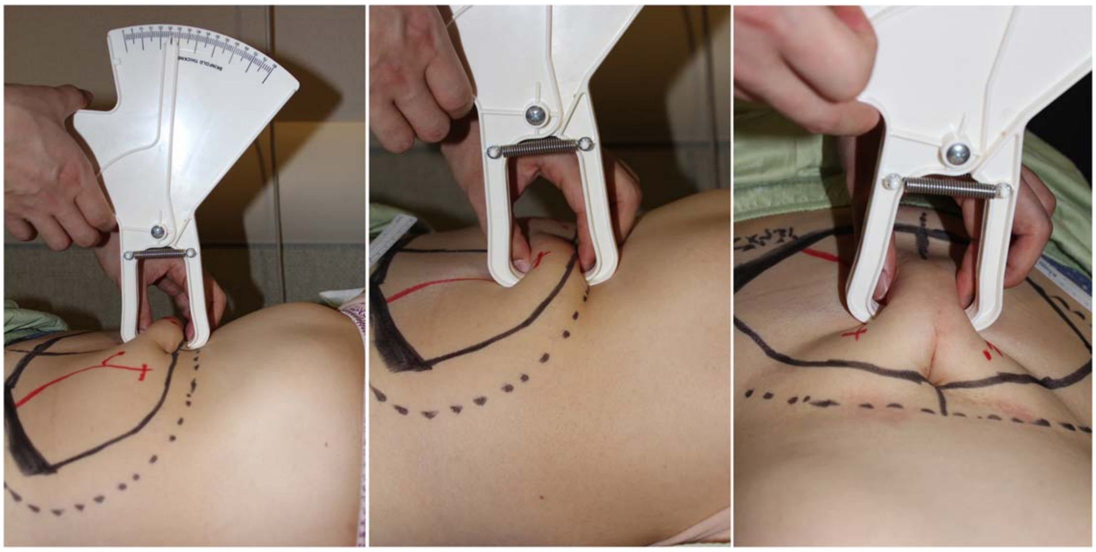

FIGURE 1 Abdominal flap pinch test at three paraumbilical sites: 5 cm right, left, and inferior to the umbilicus. (Left) Right paraumbilical flap thickness, (Center) left paraumbilical flap thickness, and (Right) inferior paraumbilical flap thickness. Thicknesses were measured using a skin-fold caliper

TABLE 1 Paraumbilical abdominal flap thickness measurements by pinch test

	CT angiography (mean ± SD)	Pinch (mean ± SD)	Ratio of pinch to CT thickness	P*
Total number of patients	107			
Body mass index, kg/m^2	23.61 ± 2.76 (range: 18.98–31.44)			
Rt. paraumbilical flap thickness (R), mm	27.58 ± 6.93	15.09 ± 4.62	0.56 ± 0.12	<.001
Lt. paraumbilical flap thickness (L), mm	26.57 ± 6.71	14.92 ± 4.48	0.57 ± 0.13	<.001
Inferior paraumbilical flap thickness (I), mm	26.25 ± 7.73	14.83 ± 4.38	0.58 ± 0.14	<.001
Flap height (H), cm	13.0 ± 0.9 (range: 11–15.5)			
Flap width (W), cm	28.4 ± 4.9 (range: 21.5–43)			
Flap weight, g	681 ± 276 (range: 284–1504)			

*Pearson's correlation analysis (correlation coefficient: $R = 0.660$, $L = 0.650$, $I = 0.678$).

3 | RESULTS

The mean BMI of the 107 patients was 23.61 ± 2.76 kg/m^2, the mean flap height was 13.0 ± 0.9 cm, and the mean flap width was 28.4 ± 4.9 cm (Table 1). The mean flap thickness as measured by the pinch test was 15.09 ± 4.62 mm for the right (R), 14.92 ± 4.48 mm for the left (L), and 14.83 ± 4.38 mm for the inferior (I) skin folds. The mean intraoperative flap weight, as measured by an electronic scale, was 681 ± 276 g (range: 284–1504 g). Flap thicknesses measured by the pinch test were significantly correlated with those measured by CT images ($P < .001$).

Rater 1, 2, and 3 performed pinch test in 33, 40, and 34 patients, respectively. We found that pinch thickness showed statistically significant correlation with CT thickness in all the three raters. The correlation coefficients and P values of the three raters are shown in the Table 2. In this study, the rater repeated pinch measurements at the three paraumbilical sites in one patient. The repeated measures ANOVA determined that the ratios of pinch thickness to CT thickness at the three paraumbilical sites were not significantly different (mean ratio: 0.56 ± 0.12, 0.57 ± 0.13, and 0.58 ± 0.14, right, left, and inferior paraumbilical sites, respectively, $P = .096$).

A prediction model with a coefficient of determination (R^2) of 89.03% was developed using multiple linear regression analysis. This model included five independent variables: BMI (kg/m^2), $(R + L)/2$ (mm), I (mm), H (cm), and W (cm). The coefficients and P values of each predictor variable are listed in Table 3. The developed formula, hereafter referred to as the DIEP-W: Pinch method, was as follows:

Flap weight (g) $= -1308 + 24.57 \times \text{BMI} + 6.80 \times (R + L)/2 + 7.89 \times I + 20.51 \times H + 32.55 \times W$ ($R^2 = 89.03\%$, $P < .001$).

To evaluate the accuracy of the developed prediction model, we performed cross-validation using leave-one-out method. The MAPE (mean absolute percentage error) and cross-validation R^2 were calculated in the cross-validation. Cross-validation R^2 is the overall correlation between predicted and observed values in the internal validation; high R^2 indicates better predictive power. In the leave-one-out cross-validation, the mean absolute percentage error was 12.15% with a cross-validation R^2 of 87.4%. This formula was also implemented in a newly developed mobile application entitled DIEP-W version 2.0,

TABLE 2 Correlations of pinch measurements with CT measurements of the three raters

	CT thickness (mean ± SD)	Pinch thickness	Correlation coefficient*	P
Rt. paraumbilical flap thickness (R), mm				
Rater 1 ($n = 33$)	25.73 ± 6.92	15.33 ± 4.96	0.670	<.001
Rater 2 ($n = 40$)	29.16 ± 6.99	15.88 ± 5.10	0.662	<.001
Rater 3 ($n = 34$)	27.51 ± 1.62	13.95 ± 3.45	0.730	<.001
Lt. paraumbilical flap thickness (L), mm				
Rater 1 ($n = 33$)	24.80 ± 6.36	15.15 ± 4.63	0.637	<.001
Rater 2 ($n = 40$)	28.08 ± 6.63	15.54 ± 5.10	0.627	<.001
Rater 3 ($n = 34$)	26.51 ± 6.90	13.98 ± 3.40	0.801	<.001
Inferior paraumbilical flap thickness (I), mm				
Rater 1 ($n = 33$)	24.36 ± 8.20	15.08 ± 4.81	0.761	<.001
Rater 2 ($n = 40$)	28.47 ± 7.38	16.23 ± 4.20	0.750	<.001
Rater 3 ($n = 34$)	25.46 ± 7.21	12.94 ± 3.50	0.485	.004

*Correlation coefficient in Pearson's correlation analysis.

TABLE 3 Multiple linear regression model for the estimation of DIEP flap weight using pinch test ($R^2 = 89.03\%$, $P < .001$)

	Coefficients*	*P*
Intercept	−1308	<.001
BMI (kg/m^2)	24.57	<.001
($R + L$)/2 (mm)	6.80	.038
I (mm)	7.89	.013
H (cm)	20.51	.090
W (cm)	32.55	<.001

Abbreviations: BMI, body mass index; *R*, right paraumbilical flap thickness; *L*, left paraumbilical flap thickness; *I*, inferior paraumbilical flap thickness; *H*, height of the flap; *W*, width of the flap.
*Adjusted for the other independent variables included in this table. All variables were selected by the Akaike information criterion (AIC).

which can currently be downloaded free of charge from Apple's online App Store and Google Play Store for quick and convenient use (Figure 2).

Scatter plots of the actual and predicted flap weights of the three prediction models are shown in Figure 3. In the DIEP-W: CT estimation method, the MAPE was 7.7 ± 5.6%, and the mean absolute error of the flap weight was 52 ± 43 g (range: 0–243 g). The MAPEs of the CT Volumetry and DIEP-W: Pinch methods were 11.1 ± 8.7% and 11.5 ± 9.0%, respectively. The mean absolute errors of the flap weights calculated by the CT Volumetry and DIEP-W: Pinch methods were 81 ± 90 g (range: 0–590 g) and 72 ± 55 g (range: 0–233 g), respectively. The absolute percentage errors were not significantly different among the rater 1, 2, and 3 (MAPE: 13.0 ± 9.9%, 9.8 ± 7.3%, and 11.9 ± 9.9%, respectively. $P = .367$).

4 | DISCUSSION

We demonstrated that DIEP flap weight for breast reconstruction can be predicted by the abdominal pinch test. Flap weight was predicted by a formula incorporating five predictor variables (BMI, mean right and left paraumbilical flap thicknesses, inferior paraumbilical flap thickness, flap height, and flap width). The prediction model had an acceptable coefficient of determination ($R^2 = 89.03\%$), and its accuracy was demonstrated by cross-validation. Regardless of the raters, the pinch thickness was significantly correlated with CT thickness. The repeated measures ANOVA showed that pinch measurement at the three different sites were consistent in terms of relative thickness compared to CT thickness.

Several studies have demonstrated that inset rate (the ratio of flap used for inset to harvested flap) is significantly associated with development of perfusion-related complications in breast reconstruction using DIEP flap (Kroll, 2000; Lee, Lee, Nam, Han, & Mun, 2015). Surgeons can estimate the inset rate when the breast volume is simultaneously calculated with the DIEP flap volume, and this estimations can help in the elaborate planning such as the number of perforators to be included, pedicle configuration (uni-pedicle or bi-pedicle), and flap size. Preoperative breast volume has been estimated by Archimedes procedure, anthropometry measurement, or a calculation formula (Kayar et al., 2011; Longo et al., 2013). Recently, 3-D surface photography can be used for breast volume measurement (Tomita et al., 2015; Vorstenbosch & Islur, 2017). When the breast volume is measured by the

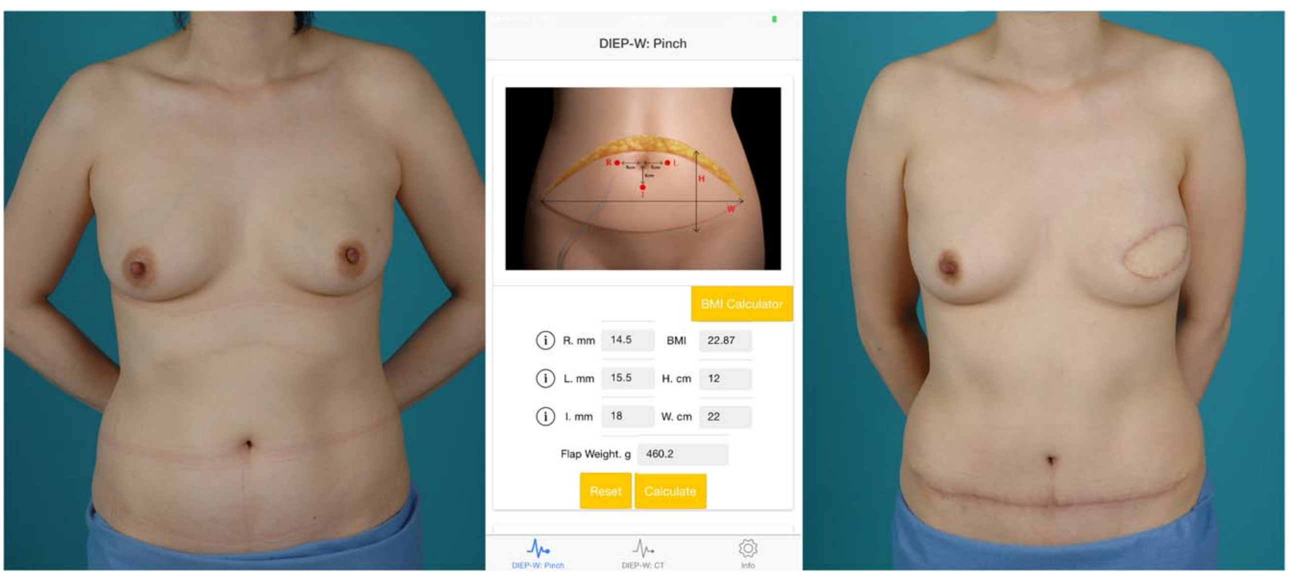

FIGURE 2 Case example of the pinch test for preoperative estimation of the weight of the abdominal flap for DIEP breast reconstruction. (Left) A lean woman with a body mass index of 22.87 kg/m^2 required immediate reconstruction of her left breast. The patient preferred autologous reconstruction to implant-based reconstruction. (Center) The R, L, and I pinch test results were 14.5, 15.5, and 18 mm, respectively. The estimated flap weight for a 12 × 22 cm DIEP flap was calculated to be 460 g by the developed smartphone application. A bipedicled DIEP flap was planned. The actual flap weight was 477 g; 439 g of the flap (92%) was used for the inset. (Right) Breasts were symmetrical at 6 months postoperation

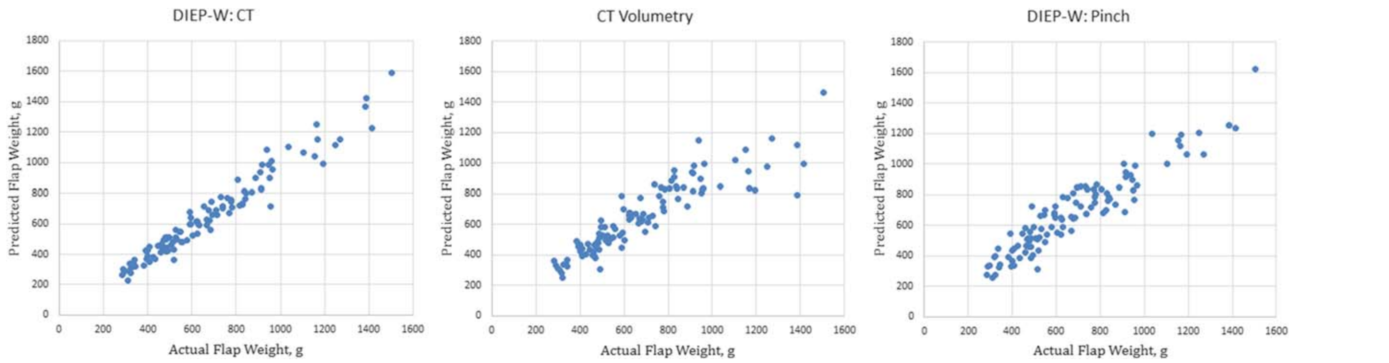

FIGURE 3 Scatter plots showing the predicted and actual flap weights according to the three different prediction methods. (Left) Flap weights estimated using the DIEP-W: CT method. The MAPE was 7.7 ± 5.6%, and the mean absolute error was 52 ± 43 g (range: 0–243 g). (Middle) Flap weights estimated using the CT volumetry method. The MAPE was 11.1 ± 8.7%, and the mean absolute error was 81 ± 90 g (range: 0–590 g). (Right) Predictions by the pinch test. The estimation outcomes were comparable to those of the CT volumetry method. The MAPE was 11.5 ± 9.0% with a mean absolute error of 72 ± 55 g (range: 0–233 g)

3-D photograph and the flap weight is estimated by the DIEP-W: Pinch method, predicted inset rate of the flap can be calculated. The authors perform a bipedicled flap using intraflap cross-over anastomosis (turbocharging) when the predicted inset rate is around 75% or over to reduce perfusion-related complications (Figure 4) (Lee & Mun, 2016). A previous study from the author's institution demonstrated that the flaps with inset rates >79% showed 16 times higher risk of fat necrosis than those below 79% (Lee et al., 2015).

Various methods have been reported for estimating abdominal flap volume for breast reconstruction. CT angiographic examination is most commonly used for 3-D volume estimation (Eder et al., 2014; Nanidis et al., 2014; Rosson et al., 2011; Tomita et al., 2015). Rosson et al. (2011) marked the outline of the DIEP flap before the CT angiographic exam and calculated the flap volume in a slice-by-slice approach using the volume rendering program. Specialized software for volume quantification using 3-D reconstructed CT angiographic images has also been introduced (Eder et al., 2014; Tomita et al., 2015). Nanidis et al. (2014) calculated DIEP flap volume using CT angiographic images based on a DIEP flap shape resembling an isosceles triangular prism. Magnetic resonance images have also been used for volume estimation (Kim et al., 2015). However, all these methods necessitate specialized software or procedures in addition to radiologic images; moreover, estimations are impossible when radiologic exams cannot be performed either due to financial or equipment limitations. Some centers never use preoperative CT angiography or MR angiographies for DIEP flap breast reconstructions. Even at a center where preoperative

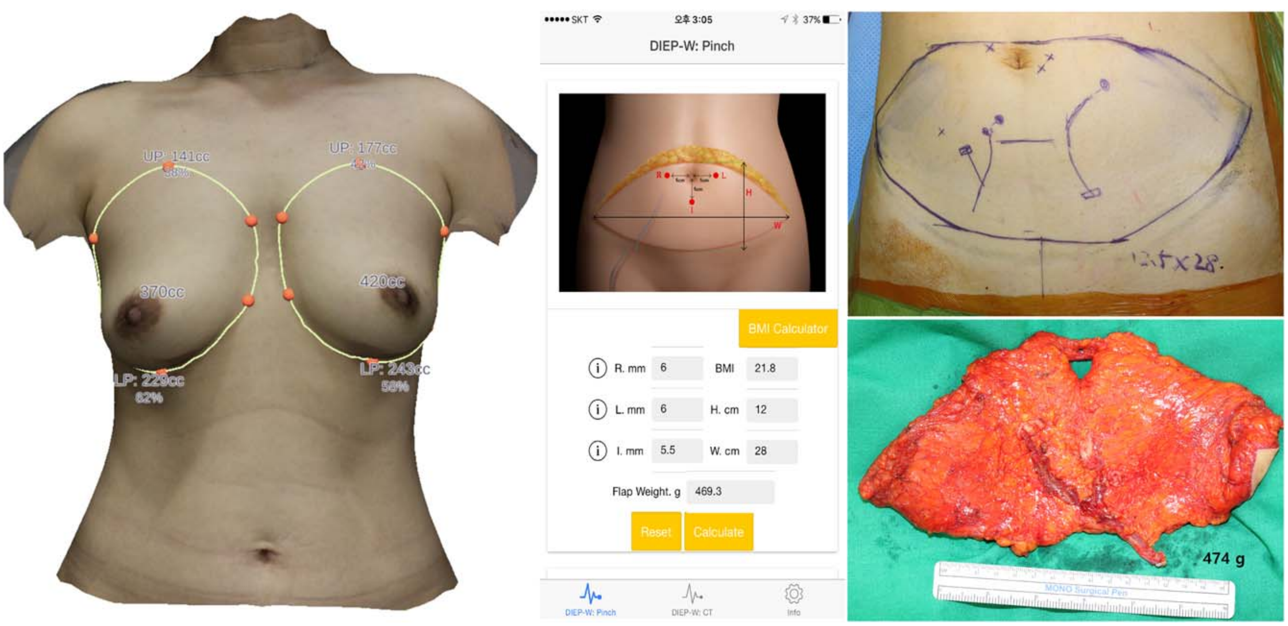

FIGURE 4 A 42-year-old woman with a body mass index of 21.8 kg/m^2 required immediate DIEP flap breast reconstruction of her left breast. (Left) The volume of the right breast was 370 cc in the 3-D photograph (Crisalix SA, Switzerland). (Center) Estimated flap weight for a 12 × 28-cm-sized DIEP flap was 469 g, giving a predicted inset rate of 78.9% (370/469). (Right) Bipedicled DIEP flap with intraflap cross-over anastomosis was planned and executed. The elevated flap weight was 474 and 390 g of the flap (82.3%) was used for the inset

CT or MR angiography is routine, the images are not available in the first consultation. The prediction model presented here can be used in the first consultation since it only requires a skin fold caliper (which costs <20 dollars), a ruler, and a smartphone running the developed application.

Mohana et al. also performed the pinch test and calculated DIEP volume by considering the flap area to be composed of two identical triangles (Mohanna & Farhadi, 2012). However, the number of patients in this study was small, and the pinch test was not reproducible given that no landmarks were reported. Longo et al. (2013) used a multiple linear regression model to estimate breast volume and reported a formula with an R^2 value of 73%, which is much lower than the value obtained in this study (89.03%). In comparison with the DIEP-W:CT model of the previous study, the developed DIEP-W:Pinch prediction model was found to be less accurate than the DIEP-W:CT approach (MAPE = 7.7% vs 11.5%) (Figure 3). Given that the pinch test was performed by three different observers and that pinch measurements are not as objective as CT measurements, we consider this amount of error to be acceptable. Furthermore, we found that the estimation outcomes of the pinch model were comparable to those of the CT Volumetry method.

Because the DIEP-W: Pinch model was developed using the same methodology as the DIEP-W: CT, higher error rates of DIEP-W: Pinch model could be caused by the pinch measurement errors. Standard and consistent pinch measurements will be essential to reduce the estimation error. The measurement should be performed with the patient in supine position because dimensions of abdomen change in standing position. A rater should grasp full thickness of the abdominal flap, measure the point midway between the top and bottom of the skin fold at the point 5 cm from the umbilicus, hold the skin folds with one hand so as not to exert counterpressure on the caliper during measurement (Supporting Information Video 1), and use a mean value of two repeated measurements. If a surgeon uses different shapes of design for DIEP flap, one can develop a tailored formula using the surgeon's own data to reduce estimation errors.

Some limitations of our prediction model are that different types of flap design, patient-to-patient variation in adipose tissue density, and unusual fat deposit distributions in the lower abdomen can reduce the accuracy of the formula. This method is not a direct measurement of the abdominal flap volume but a statistical estimation, and the pinch test is not a completely objective measurement. Therefore, we should admit that amount of error is high in some cases. Although our prediction model might be less accurate than direct measurements using CT or MR images, our method is easy, cost-effective, and does not require radiation exposure. Moreover, patients can be informed of the expected size of their reconstructed breasts with this prediction model at their first consultation.

5 | CONCLUSIONS

DIEP flap weight can be estimated by the pinch test using the prediction model developed in this study. This method will allow surgeons to refine planning of DIEP flap breast reconstructions and provide better counseling for patients when radiologic images are not available.

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SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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