



Breast Morphological Changes after Transaxillary Dual-Plane Augmentation with Smooth Round Implants: A Prospective Study

Yue Liu¹ · Jie Luan¹



Received: 6 August 2022 / Accepted: 25 September 2022 / Published online: 10 October 2022
© Springer Science+Business Media, LLC, part of Springer Nature and International Society of Aesthetic Plastic Surgery 2022

Abstract

Background Breast augmentation is the most performed cosmetic surgery in the world. Although smooth round implants are widely used, the trend in breast morphology change after dual-plane augmentation with such implants remains unclear. In this study, we analyzed the issue with the support of 3D scanning technology, which may help provide an objective basis for the evaluation of postoperative outcomes and the determination of follow-up time points.

Methods Patients undergoing dual-plane augmentation with smooth round implants were prospectively included in this study. The variation trend of postoperative breast morphology was analyzed by measuring the specified linear distance, body surface distance, breast projection, nipple position and breast volume at different follow-up time points (1st month, post-1M; 3rd month, post-3M; 6th month, post-6M; 12th month, post-12M).

Results A total of 18 patients were included in this study. During the postoperative follow-up period, breast height prolonged while interval of the medial border gradually widened. Breast width was maintained without significant alterations from post-1M. The N-MBB lengthened with shortening of the N-LBB, meanwhile the N-IMF was prolonged by 0.6 cm. Breast volume was gradually reduced with the decrease in breast projection. The position of the nipple gradually shifted laterally, superiorly, and

posteriorly after surgery. There was no statistically significant difference between the linear distance at post-3M and post-12M, while the surface distance, breast projection, nipple position and breast volume tended to be stable at post-6M.

Conclusions After dual-plane augmentation with smooth round implants, the base contour of the breast shifted outwards and downwards, and stabilized after 3 months. The remaining breast morphological parameters reached a relative steady state by post-6M, which could be regarded as the time point for objective evaluation of postoperative effect.

Level of Evidence IV This journal requires that authors assign a level of evidence to each article. For a full description of these Evidence-Based Medicine ratings, please refer to the Table of Contents or the online Instructions to Authors www.springer.com/00266.

Keywords Dual-plane augmentation · Breast morphology · Three-dimensional scanning · Smooth round implants

Introduction

According to the statistics of the International Society of Aesthetic Plastic Surgery (ISAPS) in 2020, breast augmentation is the most performed cosmetic surgery in the world [1]. The currently widely used dual-plane technique was first reported by Tebbetts [2] in 2000, which conflated the advantages of the retropectoral and the retromammary technique by dividing the pectoralis major muscle while limiting the tradeoffs and risks of a single technique. The breast implant has undergone five generations of product iterations since its introduction in the 1960s, and a

✉ Jie Luan
luanjieplastic@126.com

¹ Department of Aesthetic and Reconstructive Breast Surgery, Plastic Surgery Hospital, Chinese Academy of Medical Sciences and Peking Union Medical College, No.33 Badachu Road, Shijingshan, Beijing 100144, China

consensus has been reached on the safety and efficacy of its clinical application [3]. There are a wide variety of implants available for clinical selection, which can be divided into round and anatomic according to their shapes. The base contour of the round implant is a regular circle, and its lateral view is approximately semicircular, with the largest point of projection located in the center, while the anatomic implant has an oval base profile, and it provides more projection at the lower pole. The surface of the anatomic implant is a textured structure with different pore sizes, its original design was to enhance the adhesion to the tissue by increasing the friction coefficient and reduce the incidence of implant displacement [4]. There are two types of round implants available clinically: textured and smooth. The surface layer of the smooth round implant is made of silica gel and cured in a laminar flow oven, which is smooth and has low friction [5]. The diversification of implant types provides more choices for both surgeons and patients, and also lays the foundation for the formulation of individualized surgical plans.

Objective and accurate measurement of breast shape after augmentation is the linchpin to evaluating the effect of surgery. However, breast morphology after augmentation is not maintained at steady state but is in a dynamic change due to the interaction of the implant with glands, muscle tissue, and altered skin elasticity resulting from implant implantation [6]. It is therefore critical to clarify the trends in postoperative breast morphology and the time points at which it tends to stabilize. Three-dimensional (3D) scanning technology has been widely used in recent years for the evaluation of outcomes after mammoplasty, and its accuracy and reproducibility have been demonstrated [7–10]. The technology builds a model by creating point cloud data of the object's geometric surface and complementing it to synthesize the object's surface shape. The model can then be measured and analyzed by reverse engineering software. The results of Ji et al. [11] showed that the breast morphological parameters remained stable 6 months after dual-plane augmentation using anatomic implants. Since the surface material, implant shape and type of silicone filling of the round prosthesis are different from those of the anatomical prosthesis, the changing trend of breast shape after augmentation using this type of implant is still unclear. In this study, we analyzed the trends of breast morphology changes after dual-plane augmentation with smooth round implants, which may help provide an objective basis for the evaluation of postoperative outcomes and the determination of follow-up time points.

Materials and Methods

Patient Enrollment

This prospective study included patients who underwent endoscopic-assisted transaxillary dual-plane augmentation at our center from July 2020–June 2021. The purpose of this study and the use of the 3D scan data were fully informed preoperatively. Informed consent was obtained from all patients, the study complied with the Declaration of Helsinki, and the study protocol was approved by the ethics committee. All included patients were operated on by the same surgeon (corresponding author).

The inclusion criteria were as follows:

- (1) Diagnosed as congenital breast dysplasia;
- (2) No history of breast-related surgery;
- (3) The preoperative 3D scan was completed;
- (4) No serious systemic disease in the past, could tolerate the risks of surgery and anesthesia;
- (5) Signed the informed consent;
- (6) Selected smooth round implant.

The exclusion criteria were as follows:

- (1) Postoperative complications such as infection, hematoma, and capsular contracture that affect breast shape;
- (2) The postoperative follow-up was not completed within the specified time.

Preoperative and postoperative demographic data including age, height, and weight (used to calculate BMI) were collected for the enrolled patients. The implant model, diameter, projection, and volume were also documented.

Three-Dimensional Scanning

3D scans of the enrolled patients were obtained preoperatively and postoperatively (1 month, post-1M; 3 month, post-3M; 6 month, post-6M; 12 month, post-12M) using a noncontact 3D body scanner (JRCB-D; Jirui, Beijing, China; accuracy ≤ 0.1 mm) (Fig. 1). The 3D model was imported into the software Geomagic Wrap 2017 (3D Systems, South Carolina, USA), the X-, Y- and Z-axes were determined according to previously published methods, from which the coordinate system was established [12].

Surgical Procedure

All procedures were performed under general anesthesia, using endoscopically assisted transaxillary dual-plane

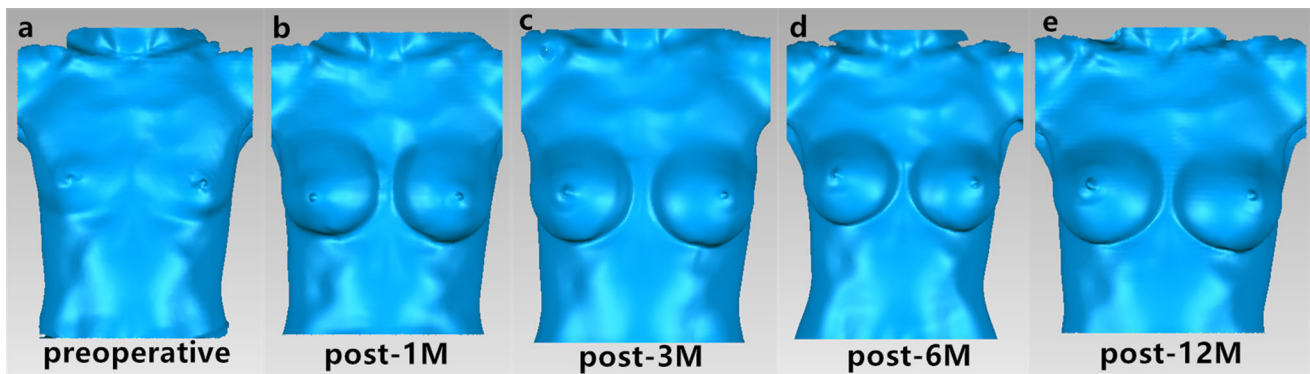


Fig. 1 Three-dimensional scan models of preoperative and postoperative follow-up time points. Post-1M, the first month after operation; post-3M, the third month after operation; post-6M, the sixth month after operation; post-12M, the twelfth month after operation

technique by the senior author (corresponding author). The pectoralis major was severed at 1.5 cm above the original inframammary fold, and the muscle remnant was released upward to move it up to the level of the lower margin of the areola.

Linear Distance Measurements

The upper breast border (UBB) was defined as a line through the sternal angle and parallel to the X-axis, and the inferior breast border (IBB) was defined as a tangent line through the nadir of the inframammary fold (IMF) and parallel to the X-axis. The vertical distance between the two borders was measured as breast basal height (BH). The tangent line through the medial breast border and parallel to the Y-axis was defined as the medial breast border (MBB), and the tangent through the lateral breast border and parallel to the Y-axis was defined as the lateral breast border (LBB), two straight lines inter-distance was

measured as breast basal width (BW). Interval of the medial border (IM) was also measured and recorded (Fig. 2).

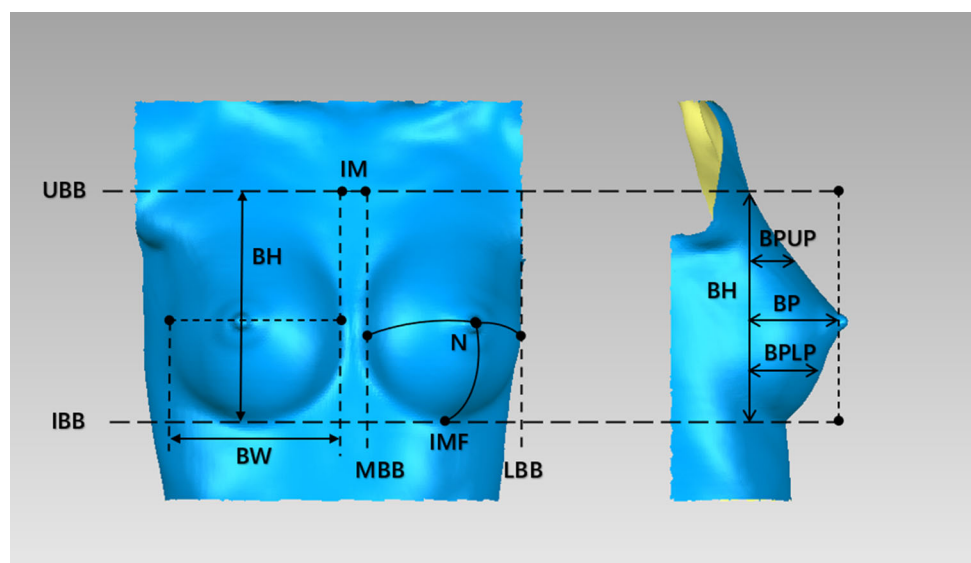
Body Surface Distance Measurements

The nipple-to-MBB (N-MBB), nipple-to-LBB (N-LBB), and nipple-to- inframammary fold (N-IMF) surface distances were measured, respectively (Fig. 2).

Breast Projection

The XY plane through the sternal angle was defined as the base of the breast, and the vertical distance from the base of the nipple to this plane was defined as the breast projection (BP). Breast projection of upper pole (BPUP) and breast projection of lower pole (BPLP) were measured at the midpoint of the upper and lower hemispheres of the breast, respectively (Fig. 2).

Fig. 2 Breast linear distance, body surface distance and projection measurements. UBB, upper breast border; IBB, inferior breast border; MBB, medial breast border; LBB, lateral breast border; BH, breast height; BW, breast width; IM, interval of the medial border; N, nipple; IMF, inframammary fold; BP, breast projection; BPUP, breast projection of upper pole; BPLP, breast projection of lower pole



Nipple Position

The measurement function of the software was used to record the coordinates of the nipple on the X-, Y- and Z-axes, and then analyze the movement of the nipple position at each follow-up time point.

Breast Volume

The postoperative model was initially aligned with the preoperative model using the “Best Fit Alignment” function of the Geomagic software, and then a simulated chest wall was established based on the preoperative model [13]. Select the breast area in the postoperative 3D model and use the “Trimming with a Sheet” function to obtain a cylinder-like shape with the breast as the superface. The cylinder model was fine-tuned by the “Object Mover” so that its boundaries achieved adequate alignment with the simulated chest wall. A cylinder-like model with simulated chest wall surface is obtained by Boolean operation. The function of “Filling Individual Holes” was used to seal the bottom surface of the quasi-cylinder and calculate the volume of the two cylinders, respectively. The value

obtained by subtracting the two cylinders was regarded as the breast volume (BV) (Fig. 3).

With the “Trimming With a Plane” function, the XZ plane was adjusted to the level of the nipple to trim the composite model of Fig. 3g. Delete the lower half of the selection and close the intersection surface (Fig. 4). The model volumes of the two trimmed cylinders were calculated, respectively, and the half-pole volume of the breast could be obtained by subtracting (breast volume of upper pole, BVUP; breast volume of lower pole, BVLP). Calculate the ratio of upper and lower breast volume (BVUP/BV, BVLP/BV).

Three-Dimensional Compare

3D comparisons of models at postoperative time points were performed using Geomagic Qualify 2013 (3D Systems, South Carolina, USA) software. The post-12M 3D model was set as the reference, and the 3D models of post-1M, post-3M and post-6M were set as the test data successively. Use the function “3D Compare” to measure the shape deviation between the reference object and the test object, that is, the shortest distance between any point of

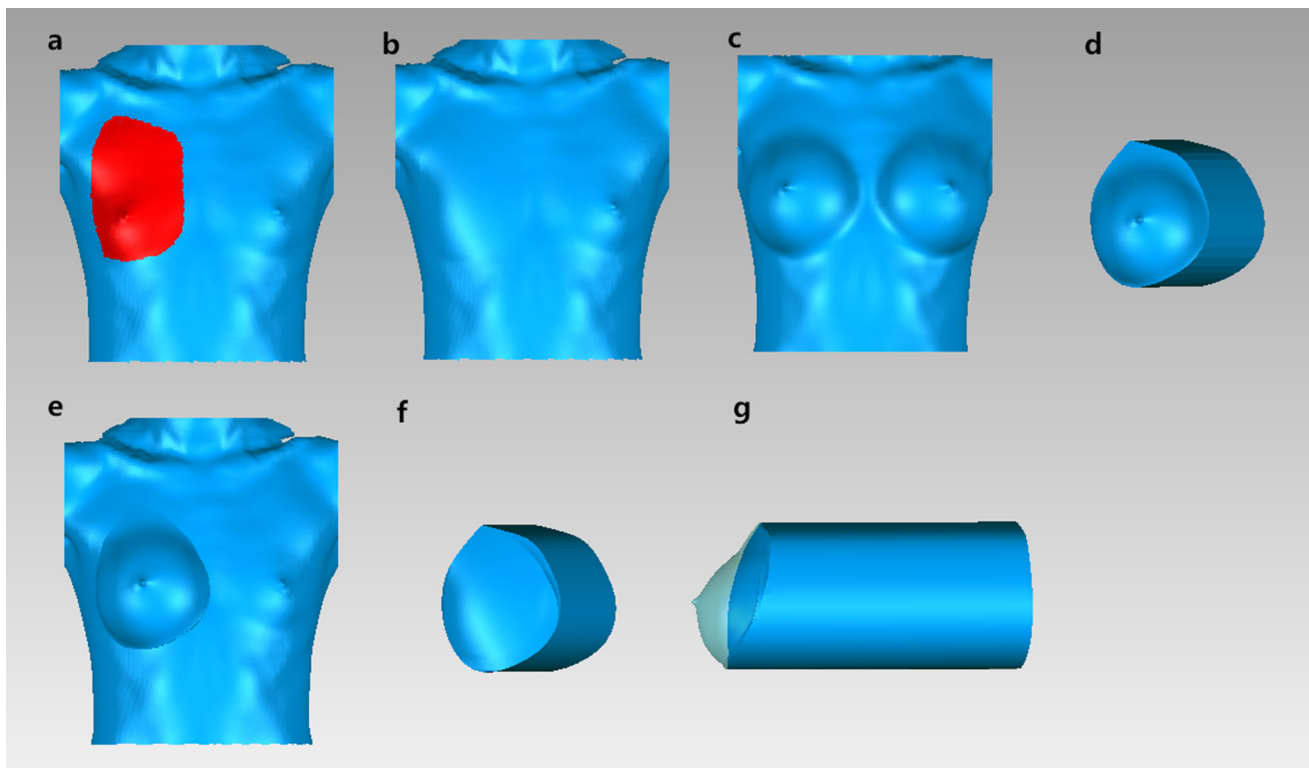


Fig. 3 **a** Select the breast area in the preoperative 3D model; **b** Delete the selection and use the function “Fill Hole based on Curvature” to form a simulated chest wall; **c** & **d** Select the breast area in the postoperative 3D model and use the “Trimming with a Sheet” function to obtain a cylinder-like shape with the breast as the

superface. **e** The cylinder model was fine-tuned by the “Object Mover” so that its boundaries achieved adequate alignment with the simulated chest wall. **f** A cylinder-like model with simulated chest wall surface is obtained by Boolean operation. **g** The value obtained by subtracting the two cylinders was regarded as the breast volume

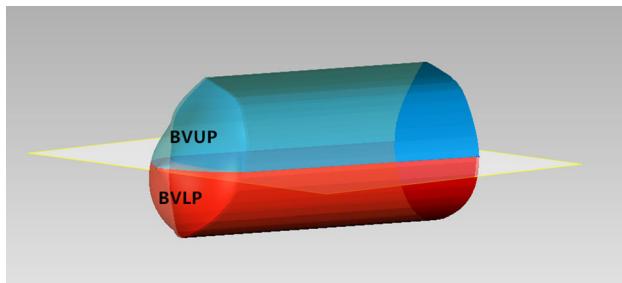


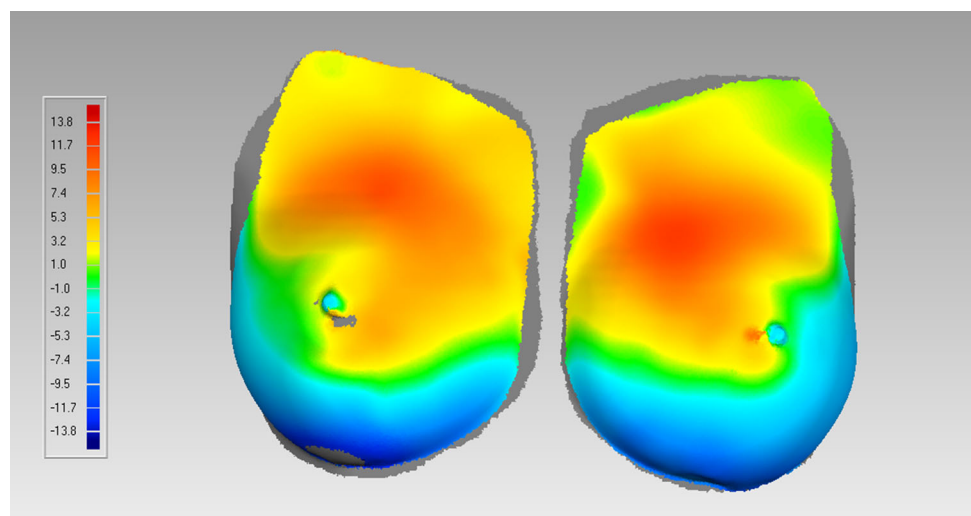
Fig. 4 The two cylindrical models were divided into upper and lower poles by “Trimming With a Plane” function, and their volumes were calculated, respectively. BVUP, breast volume of upper pole; BVLP, breast volume of lower pole

the two objects. Max. Nominal and Min. Nominal were specified as ± 1 mm, the output results were presented as deviation spectrum, and the percentage of 3D deviation outside the range of Max-Nominal and Min. Nominal was calculated (Fig. 5).

Statistical Analysis

The measurement data were presented as mean \pm standard deviation (SD). Data comparisons at different time points were analyzed using one-way repeated measures ANOVA with Mauchly’s test of sphericity, the within group effect *F* values were corrected with the Greenhouse–Geisser method if the Mauchly’s test was not met. Polynomial method was used to compare the fluctuation trend at different postoperative time. Multiple comparisons of data at each time point were performed using post hoc tests by the Bonferroni method. Consistency tests were performed using the intraclass correlation coefficient (ICC). Statistical analysis was performed using Statistical Product Service Solutions 26.0 (SPSS, IBM Corporation, Illinois, USA),

Fig. 5 Three-dimensional deviation chromatogram, Max. Nominal and Min. Nominal were specified as ± 1 mm



two-tailed significance test was selected, and a *P* value less than 0.05 was considered statistically significant.

Results

Demographics and Implant Parameters

A total of 18 patients with breast dysplasia (36 breasts) were included in this study. The mean age of the patients was 31 ± 5.5 years (22–40 years), and the preoperative body mass index (BMI) was 19.9 ± 2.8 kg/m² (17.3–25.4 kg/m²). There were no significant differences in the BMI values of patients at each follow-up time point.

The implants used in the enrolled patients were all smooth round implants (MENTOR® MemoryGel® Breast Implants, Johnson & Johnson, New Jersey, USA), including 20 High Profile Gel Breast Implants and 16 Moderate Plus Profile Gel Breast Implants. The mean implant volume (IV) was 281.3 ± 24.2 cc (250–325 cc), the mean implant diameter (ID) was 11.3 ± 0.5 cm (10.5–12.3 cm), and the mean implant projection (IP) was 4.0 ± 0.5 cm (3.4–4.6 cm) (Table 1).

Linear Distances

During the postoperative follow-up period, BH prolonged by an average of 0.4 cm while IM gradually widened by 0.4 cm, a trend that was most pronounced between post-1M and post-3M and stabilized at post-3M. BW was maintained without significant alterations from post-1M ($P = 0.197$) (Fig. 6) (Table 2).

Table 1 Mean±standard deviation (SD) of demographics and implant parameters

	Mean±SD	Range
<i>Demographics</i>		
Age (y)	31 ± 5.5	22–40
BMI (kg/m ²)	19.9 ± 2.8	17.3–25.4
<i>Implant parameters</i>		
Volume (cc)	281.3 ± 24.2	250–325
Diameter (cm)	11.3 ± 0.5	10.5–12.3
Projection (cm)	4.0 ± 0.5	3.4–4.6

Body Surface Distances

The N-MBB lengthened by an average of 0.5 cm during post-1M–post-12M with shortening of the N-LBB. The values of change during post-1M–post-6M were statistically significant. N-IMF was prolonged by 0.6 cm, and the most significant change was emerged in post-1M to post-3M period ($P = 0.000$). There was no statistical difference between post-6M and post-12M surface-distance measurements (Fig. 7) (Table 3).

Fig. 6 Variation trend of mean linear distances over the follow-up period. *, Compared with post-12M data, the difference between groups was statistically significant. ns, Compared with post-12M data, there was no statistical difference between the groups

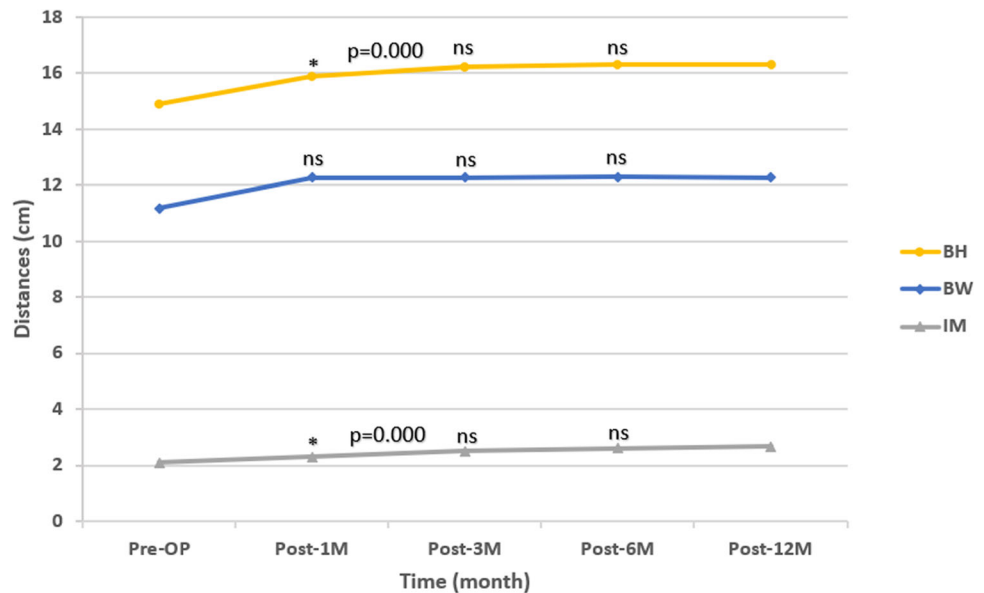


Table 2 Linear distance measurements at preoperative and postoperative follow-up time points (mean ± SD)

Linear distance (cm)	Preoperative	Postoperative			
		1M	3M	6M	12M
BH	14.9 ± 1.2	15.9 ± 0.9	16.2 ± 0.9	16.3 ± 1.0	16.3 ± 1.0
BW	11.2 ± 0.9	12.3 ± 0.6	12.3 ± 0.5	12.3 ± 0.6	12.3 ± 0.5
IM	2.1 ± 0.4	2.3 ± 0.5	2.5 ± 0.6	2.6 ± 0.6	2.7 ± 0.6

BH breast basal height, BW breast basal width, IM interval of the medial border

Breast Projection

Breast projection was gradually reduced by 0.5 cm post-operatively, which was accompanied by a decrease in BPUP and an increase in BPLP. This deformation was most pronounced postoperatively from the 1st to the 3rd month, then gradually stabilized, and the statistical difference in the measurements at the 6th versus the 12th month was already insignificant (Fig. 8) (Table 4).

Nipple Position

Compared with the preoperative coordinate values, the X-axis value of the nipple position increased, the Y-axis value decreased, and the Z-axis value increased, indicating that the nipple was displaced laterally, superiorly, and anteriorly. During the postoperative follow-up period, the position of the nipple gradually shifted laterally, superiorly, and posteriorly, and this change stabilized by the sixth month after surgery (Fig. 9) (Table 5).

Fig. 7 Variation trend of mean body surface distances over the follow-up period

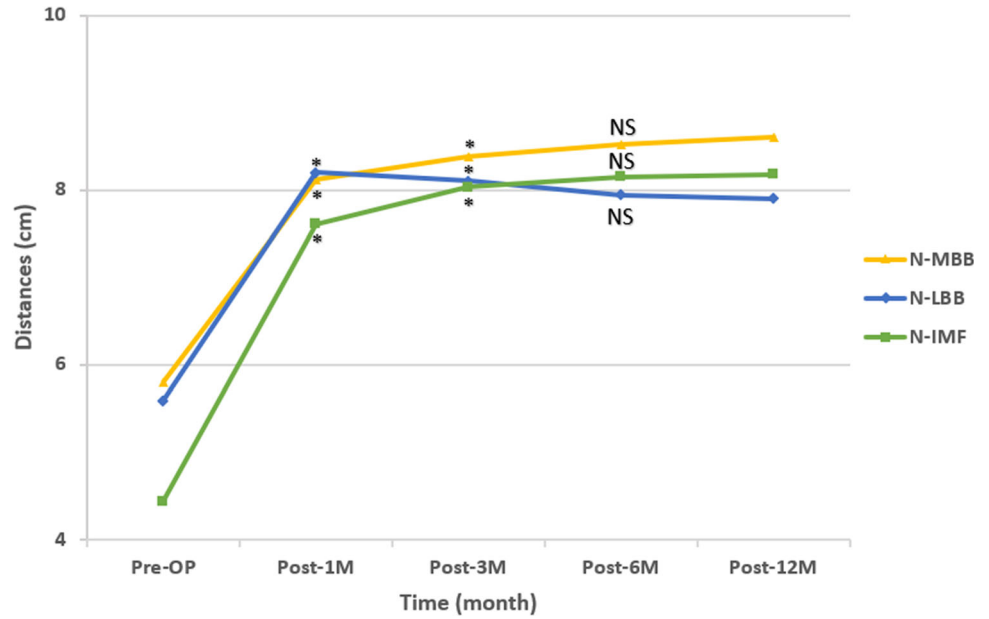


Table 3 Surface distance measurements at preoperative and postoperative follow-up time points (mean ± SD)

Surface distance (cm)	Preoperative	Postoperative			
		1M	3M	6M	12M
N-MBB	5.8 ± 0.6	8.1 ± 0.7	8.4 ± 0.6	8.5 ± 0.6	8.6 ± 0.7
N-LBB	5.6 ± 0.4	8.2 ± 0.7	8.1 ± 0.8	7.9 ± 0.8	7.9 ± 0.8
N-IMF	4.4 ± 0.5	7.6 ± 0.8	8.0 ± 0.9	8.2 ± 0.9	8.2 ± 0.9

N-MBB the nipple to the medial breast border, *N-LBB* the nipple to the lateral breast border, *N-IMF* the nipple to the inframammary fold

Fig. 8 Variation trend of mean projection over the follow-up period

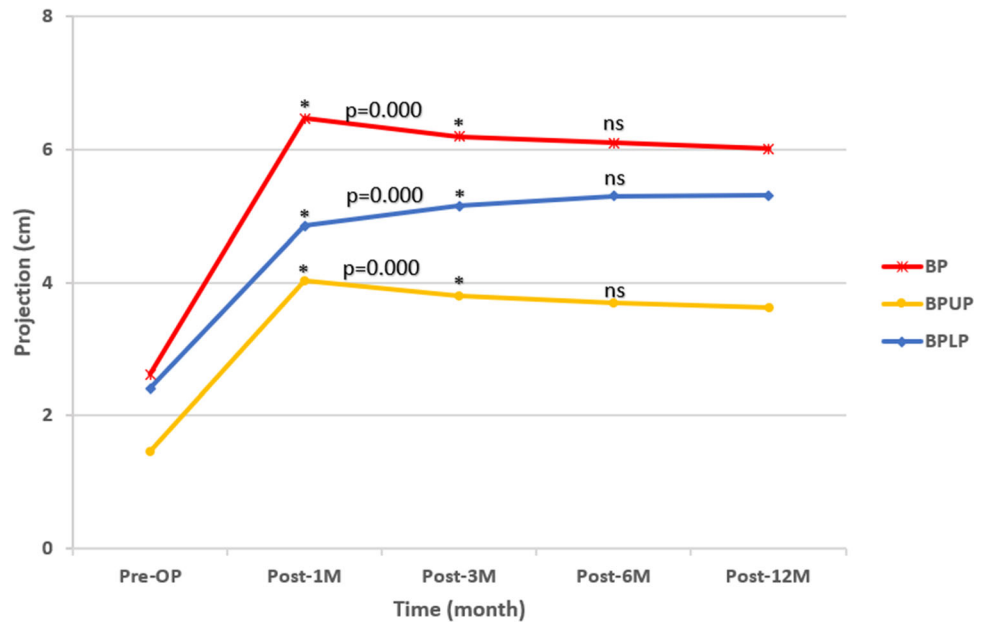


Table 4 Preoperative and postoperative breast projection measurements at each follow-up time point (mean ± SD)

Projection (cm)	Preoperative	Postoperative			
		1M	3M	6M	12M
BP	2.6 ± 0.6	6.5 ± 0.5	6.2 ± 0.5	6.1 ± 0.5	6.0 ± 0.6
BPUP	1.5 ± 0.8	4.0 ± 0.6	3.8 ± 0.6	3.7 ± 0.6	3.6 ± 0.6
BPLP	2.4 ± 1.0	4.9 ± 0.9	5.2 ± 0.9	5.3 ± 0.9	5.3 ± 0.9

BP breast projection, BPUP breast projection of upper pole, BPLP breast projection of lower pole

Fig. 9 Variation trend of nipple position coordinates over the follow-up period

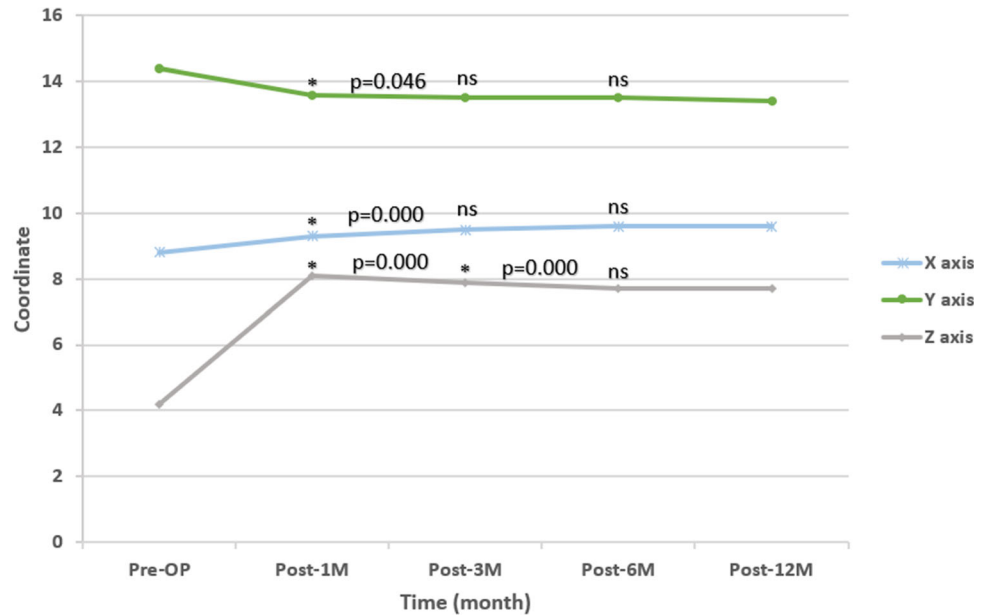


Table 5 Preoperative and postoperative nipple position coordinates at each follow-up time point (mean ± SD)

Coordinates	Preoperative	Postoperative			
		1M	3M	6M	12M
X-axis	8.8 ± 0.8	9.3 ± 0.7	9.5 ± 0.8	9.6 ± 0.8	9.6 ± 0.8
Y-axis	14.4 ± 1.3	13.6 ± 1.4	13.5 ± 1.4	13.5 ± 1.4	13.4 ± 1.4
Z-axis	4.2 ± 0.8	8.1 ± 1.0	7.9 ± 1.0	7.7 ± 1.1	7.7 ± 1.0

Breast Volume

The mean preoperative BV was 56.7 ± 11.5 cc, which increased to 308.5 ± 24.3 cc after insertion of the implant. During the follow-up period, the breast volume has been progressively reduced, and the BV of post-12M has decreased by 27.4 cc compared to post-1M. The most perceptible changes in volume occurred during post-1M to post-3M, and there was no significant difference in post-6M compared with post-12M.

The reduction in BV was followed by the redistribution of BVUP and BVLP, which was characterized by a decrease in the proportion of BVUP and a gradual rise in BVLP.

The ratio of BV reduction in each follow-up period to total volume reduction was defined as breast volume reduction rate (BVRR):

$$BVRR = \frac{\text{post-1M} - \text{post-N}}{\text{post-1M} - \text{post-12M}}$$

The calculated BVRRs of post-1M, post-3M, post-6M, and post-12M were 0, 76.6, 94.9, and 100%, respectively (Fig. 10) (Table 6).

3D Deviation

Taking the post-12M model as a reference, the mean post-1M, post-3M, and post-6M 3D deviations were 78.4 ± 0.5, 19.3 ± 3.6, and 6.1 ± 1.8 %, respectively.

Fig. 10 Variation trend of breast volume over the follow-up period. Breast volume was gradually reduced postoperatively, with the most significant reduction occurring between post-1M and post-3M. The volume proportion of the upper pole of the breast gradually decreased, and the proportion of the lower pole gradually increased

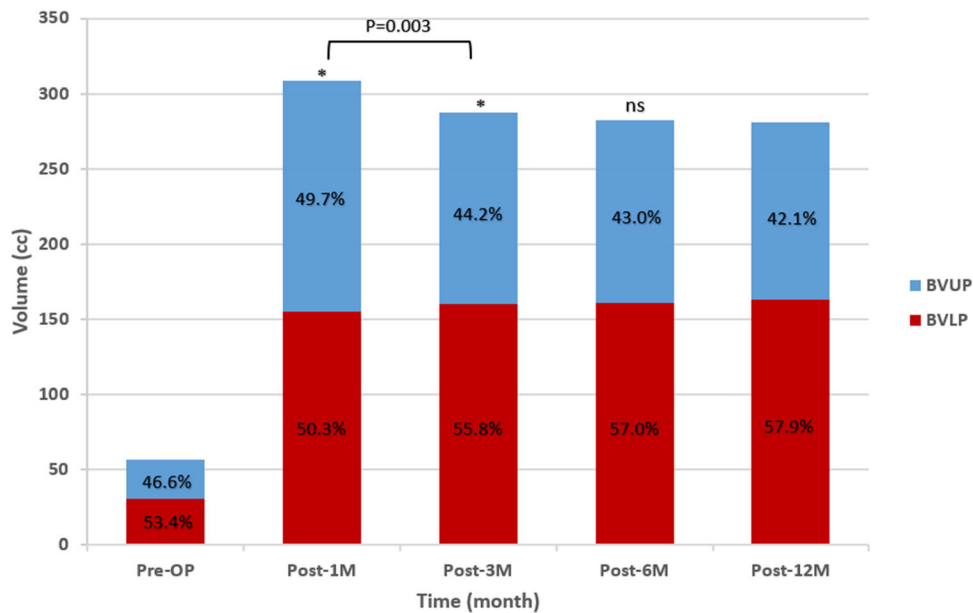


Table 6 Preoperative and postoperative breast volume at each follow-up time point (mean ± SD)

Volume (cc)	Preoperative	Postoperative			
		1M	3M	6M	12M
BV	56.7 ± 11.5	308.5 ± 24.3	287.5 ± 27.9	282.5 ± 23.5	281.1 ± 23.6
BVUP	26.4 ± 5.6	153.4 ± 7.8	127.0 ± 8.8	121.5 ± 9.5	118.3 ± 10.9
BVUP/BV (%)	46.6 ± 4.1	49.7 ± 4.1	44.2 ± 3.9	43.0 ± 3.8	42.1 ± 4.2
BVLP	30.4 ± 6.8	155.1 ± 23.5	160.5 ± 22.2	161.0 ± 19.8	162.8 ± 20.6
BVLP/BV (%)	53.4 ± 4.1	50.3 ± 4.1	55.8 ± 3.9	57.0 ± 3.8	57.9 ± 4.2
BVRR (%)	/	0	76.6	94.9	100

BV breast volume, BVUP breast volume of upper pole, BVLP breast volume of lower pole, BVRR breast volume reduction rate

The ratio of 3D deviation reduction in each follow-up period to post-1M 3D deviation was defined as the breast 3D deviation reduction rate (3DDRR).

$$3DDRR = (\text{post-1M} - \text{post-N}) / \text{post-1M}$$

The calculated 3DDRRs of post-1M, post-3M, post-6M, and post-12M were 0, 75.4, 92.2, and 100%, respectively (Fig. 11) (Table 7).

The consistency test of BVRR and 3DDRR obtained the intraclass correlation coefficient (ICC) of 0.998 ($P = 0.000$), indicating that the measurement results of the

Table 7 Postoperative 3D deviation and 3D deviation reduction rate

	Postoperative			
	1M	3M	6M	12M
3DD (%)	78.4 ± 0.5	19.3 ± 3.6	6.1 ± 1.8	0
3DDRR (%)	0	75.4	92.2	100

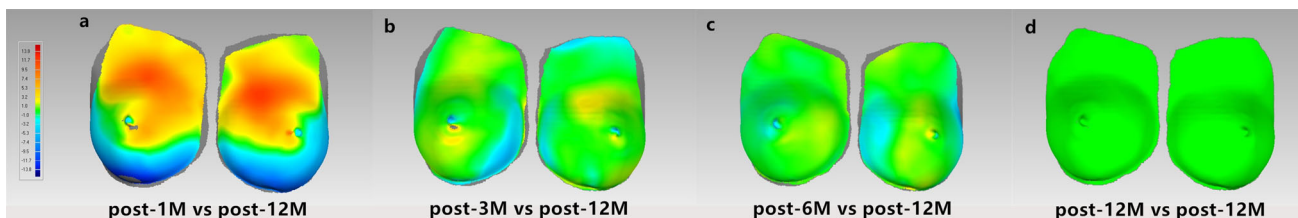


Fig. 11 Taking the post-12M model as a reference, the mean post-1M, post-3M, and post-6M 3D deviations were 78.4 ± 0.5, 19.3 ± 3.6, and 6.1 ± 1.8%

two breast morphological changes were highly consistent (Fig. 12).

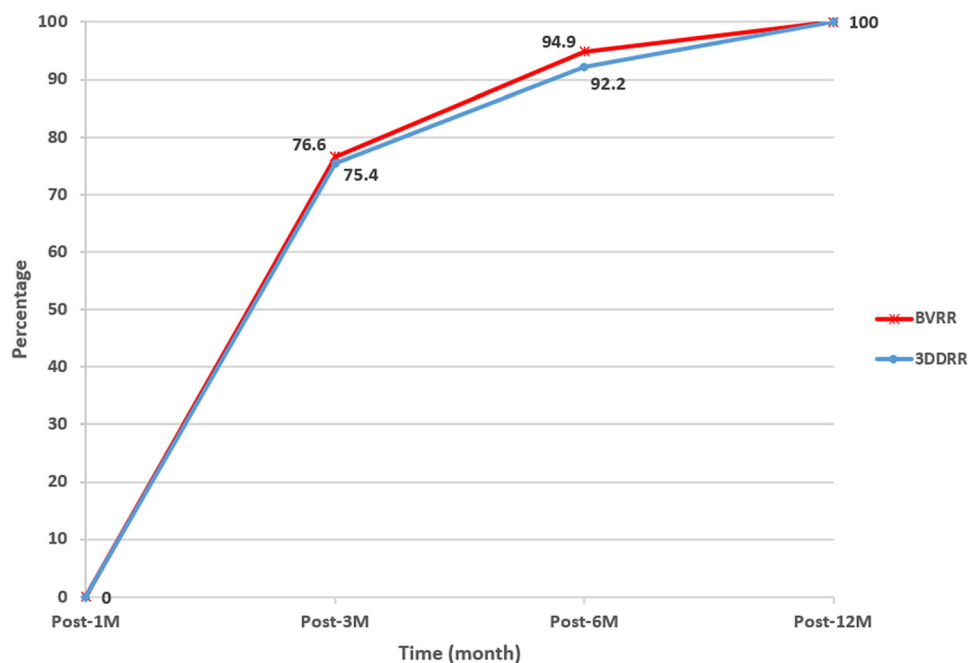
Discussion

Breast morphology is the crux to evaluating the effect of augmentation mammoplasty, while accurate and objective measurement of breast shape is the premise of assessing the effect of surgery. Breast implant is made of silicone material with certain viscoelasticity. After implantation, it will interact with muscle, mammary gland and skin tissue to different degrees according to the implantation level, resulting in dynamic changes of breast shape to a certain extent [6]. Eder et al. [14] found that breast contour and volume tended to be stable 3 months after surgery, which was concluded through 6-month follow-up of patients who received subpectoral breast augmentation with round implants. As the pectoral muscle and fascia tissue have an elastic modulus of about 100–2000 kpa, they exert an internal pressure on the prosthesis and ultimately affect the breast morphology [15]. Compared with the subpectoral technique, the dual-plane technique releases the tension of the muscles borne by the lower pole of the implant by severing the pectoralis major, and the implant can fully expand the lower pole to obtain a natural breast appearance. The surgical technique we used was a modification of the traditional dual-plane technique, that is, the pectoralis major was divided at a higher position, 1.5 cm above the original IMF. The pectoralis muscle was then pulled cephalad to the level of the areola through a special

retractor. When the pectoralis muscle is transected, the implant loses the complete coverage of the muscle and its stress is applied mainly to the glands and skin at the lower pole of the breast, which gradually causes gland atrophy, thinning of the subcutaneous tissue, and stretching of the lower pole over time [16–18], ultimately have an impact on the overall morphology of the breast. Analysis of trends in postoperative breast deformation is essential to develop follow-up plans and evaluate surgical outcomes.

The advent of 3D scanning technology has provided a novel method for breast morphology research, and this technology has been widely used in clinical practice in recent years [7, 8, 10, 11]. This study comprehensively analyzed the dynamic changes of breast morphology after augmentation with smooth round implant from four aspects: breast linear distance, body surface distance, breast projection, and breast volume. The linear parameters we selected included BH, BW and IM, which mainly reflected the displacement of the breast base contour. The UBB is marked by palpation of the sternal angle before scanning, and the boundary is a relatively fixed position, so the change of BH after surgery mainly reflects the displacement of the IBB. The fluctuation of the IM measurement value reflects the displacement of the MBB, and the positional movement of the LBB can be estimated by combining the BW change. The results showed that the measured values of BH, BW, and IM increased significantly at 1 month after operation, indicating that the contour of the breast base was shifted outward and downward as a whole compared with the preoperative one. From the first month to the 12th month after the operation, the BH

Fig. 12 Trend plot of breast volume reduction rate (BVRR) and 3D deviation reduction rate (3DDRR) during the postoperative follow-up period



and IM gradually increased, and the BW remained basically stable, manifesting that the breast contour still maintained this shifting trend during the postoperative follow-up period. The most significant displacement occurred from the 1st month to the 3rd month after surgery, and the position of the breast contour tended to be stable thereafter, which means that the time of stabilization of the breast contour after dual-plane augmentation is basically the same as that after subpectoral augmentation. In Eder's study [14], the IMF decreased by 0.4 cm during the 6-month postoperative period. Ji et al. [11] conducted a 12-month follow-up of patients with dual-plane augmentation using anatomical implants, and the results showed that the IMF dropped by 0.5 cm after surgery, which was approximate to the results of our study (0.4 ± 0.3 cm). It is suggested that the use of smooth round implants and the amputation of pectoralis major did not increase the risk of implant displacement in the early postoperative period (12 months). It is worth emphasizing that if breast augmentation is performed through the IMF incision and IMF fixation is performed, it is theoretically possible to avoid the downward movement of the IMF. While there is still a lack of reliable evidence for this inference, further long-term follow-up studies are needed to clarify this issue.

We observed the dynamic changes of breast surface contour by measuring the surface distances N-MBB, N-LBB and N-IMF. The results showed that N-MBB was gradually prolonged and N-LBB was gradually shortened with time postoperatively, that is, the breast appeared to rotate from the inside to the outside around the Y-axis. The change was most significant from the first to the third month after surgery, and tended to be stable from the sixth month after surgery. Previous studies have shown that skin has an elastic modulus of 200–3000 kpa [19]. In the initial stage of stress expansion, collagen fibers are arranged parallel to the stretching direction, while elastin and proteoglycan matrix can both resist deformation, and skin hardness does not increase significantly. Therefore, the change of body surface distance is most significant in the early postoperative period (post-1M to post-3M). When the collagen fibers are fully aligned, the further extension of the skin requires the extension of the collagen fibers, which leads to the increase in skin hardness and the decrease in skin dilatibility [20–22], and the deformation gradually becomes stable.

Breast volume is an indispensable factor in the evaluation of surgical effect. In the system of breast measurement parameters, the volume can be regarded as the result of the change of specific measurement indicators. Specifically, in the case of breast augmentation, the change of volume is often accompanied by the increase or decrease in surface distances and breast projection. Our results showed that during the follow-up period, the total breast volume

gradually decreased, while the proportion of BVUP decreased and the proportion of the BVLP increased, indicating that the overall reduction in the breast was accompanied by volume transfer from the upper pole to the lower pole. In the 3D contrast chromatogram, it was also found that in the early postoperative period, the upper pole of the breast mainly showed positive deviation, while the lower pole of the breast showed negative deviation, which was consistent with the volume measurement results. Weck roxo [18] et al proposed that when the implant was placed in different anatomical levels, its effects on tissues were not consistent. When it was placed subpectoral, the volume of the mammary gland would not change significantly, and the main volume reduction occurred in the pectoralis muscle. While, when the implant was placed in the retro-mammary plane, the gland tissue would appear to atrophy significantly. Benito-Ruiz et al [29] had researched the thickness at the upper and lower poles along the meridian of each breast by ultrasound and found that the implant had a significant effect on the thickness of the glandular tissue, with round implants producing more atrophy in the superior pole. Studies have shown that gland atrophy is mainly caused by vascular compression and decreased hemoperfusion [23, 24], while pectoralis major atrophy is mainly caused by muscle cell damage, myofiber loss and focal myofiber degeneration caused by constant pressure [25–27]. The continuity of the pectoralis major in dual-plane augmentation has been disrupted and the tension is released, so the implant puts pressure on both the muscle and the gland simultaneously. Therefore, we speculate that the reduction in postoperative breast volume comes from both muscle and glandular tissue. By observing the variation in breast volume at different times, we found that the most significant volume reduction in the follow-up period occurred between post-1M and post-3M, which was corresponding to the linear and surface measurements, and the major volume change occurred in the upper pole of the breast. Furthermore, the variation of breast volume distribution was accompanied by corresponding changes of BPUP and BPLP.

The present study has the following limitations. Firstly, the follow-up period was relatively short. Only patients with a follow-up period of 12 months were included in this study, although the findings suggest that the overall breast morphology has stabilized by the 6th month after operation, human skin will gradually age and affect breast morphology under the influence of internal and external factors [28]; therefore breast morphological changes in the long-term postoperative period remain to be further investigated. Secondly, the sample size included in this study is relatively small, which inevitably affects the accuracy of statistical results to a certain extent. Thirdly, limited by the sample size, there was no separate grouping

according to the subtype of implant in this study. Therefore, whether the breast morphology changes after augmentation with different types of implants are consistent needs further research to determine. In addition, the patients enrolled in this study were all patients with breast dysplasia with relatively low BMI values, so it is unclear whether the conclusions can be deduced to other types of patients. Lastly, the small average volume and narrow volume distribution of the implants used may affect the applicability of the statistical results to a certain extent.

Conclusions

After dual-plane augmentation with smooth round implants, the base contour of the breast shifted outwards and downwards, and stabilized after 3 months. The position of the nipple gradually shifted laterally, superiorly, and posteriorly, and stabilized by the sixth month after surgery. The postoperative breast volume gradually decreased, while the proportion of the upper pole reduced and the proportion of the lower pole increased. The most obvious stage of variation occurred from post-1M to post-3M, and gradually stabilized until the 6th month, which could be regarded as the time point for objective evaluation of postoperative effect.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent All participants have given informed consent in writing prior to inclusion in the study.

References

- International Society of Aesthetic Plastic Surgery (2020) ISAPS Global survey results. https://www.isaps.org/wp-content/uploads/2022/01/ISAPS-Global-Survey_2020.pdf
- Tebbetts JB (2001) Dual plane breast augmentation: optimizing implant-soft-tissue relationships in a wide range of breast types. *Plast Reconstr Surg* 107(5):1255–1272. <https://doi.org/10.1097/0006534-200104150-00027>
- Mohebbali K, Wixtrom RN (2018) Breast implant engineering and performance. *Plast Reconstr Surg* 142:6S–11S. <https://doi.org/10.1097/PRS.0000000000004997>
- Derby BM, Codner MA (2015) Textured silicone breast implant use in primary augmentation: core data update and review. *Plast Reconstr Surg* 135(1):113–124. <https://doi.org/10.1097/PRS.0000000000000832>
- Barr S, Hill E, Bayat A (2009) Current implant surface technology: an examination of their nanostructure and their influence on fibroblast alignment and biocompatibility. *Eplasty* 9:e22
- Vegas MR, Martin del Yerro JL (2013) Stiffness compliance resilience and creep deformation: understanding implant-soft tissue dynamics in the augmented breast: fundamentals based on materials science. *Aesthetic Plast Surg* 37(5):922–930. <https://doi.org/10.1007/s00266-013-0197-y>
- Lin F, Hong W, Zeng L, Kong X, Feng W, Luo S (2020) A prospective study of breast morphological changes and the correlative factors after periareolar dual-plane augmentation mammoplasty with anatomic implant. *Aesthetic Plast Surg* 44(6):1965–1976. <https://doi.org/10.1007/s00266-020-01665-7>
- Tong OLH, Chamson-Reig A, Yip LCM, Brackstone M, Diop M, Carson JLL (2020) Structured light surface scanning system to evaluate breast morphology in standing and supine positions. *Sci Rep* 10(1):1–2. <https://doi.org/10.1038/s41598-020-70476-2>
- Chen L, Sun J, Mu D, Liu C, Luan J (2020) What makes a difference? Three-dimensional morphological study of parameters that determine breast Aesthetics. *Aesthetic Plast Surg* 44(2):315–322. <https://doi.org/10.1007/s00266-019-01426-1>
- Liu C, Luan J, Ji K, Sun J (2012) Measuring volumetric change after augmentation mammoplasty using a three-dimensional scanning technique: an innovative method. *Aesthetic Plast Surg* 36(5):1134–1139. <https://doi.org/10.1007/s00266-012-9944-8>
- Ji K, Luan J, Liu C et al (2014) A prospective study of breast dynamic morphological changes after dual-plane augmentation mammoplasty with 3D scanning technique. *PLoS One* 9(3):93010. <https://doi.org/10.1371/journal.pone.0093010>
- Liu C, Luan J, Mu L, Ji K (2010) The role of three-dimensional scanning technique in evaluation of breast asymmetry in breast augmentation: a 100-case study. *Plast Reconstr Surg* 126(6):2125–2132. <https://doi.org/10.1097/PRS.0b013e3181f46ec6>
- Kovacs L, Eder M, Hollweck R et al (2006) New aspects of breast volume measurement using 3-dimensional surface imaging. *Ann Plast Surg* 57(6):602–610. <https://doi.org/10.1097/01.sap.0000235455.21775.6a>
- Eder M, Waldenfels FV, Sichtermann M et al (2011) Three-dimensional evaluation of breast contour and volume changes following subpectoral augmentation mammoplasty over 6 months. *J Plast Reconstr Aesthet Surg* 64(9):1152–1160. <https://doi.org/10.1016/j.bjps.2011.03.037>
- Samani A, Bishop J, Yaffe MJ, Plewes DB (2001) Biomechanical 3-D finite element modeling of the human breast using MRI data. *IEEE Trans Med Imag* 20(4):271–279. <https://doi.org/10.1109/42.921476>
- Codner MA, Cohen AT, Hester TR (2001) Complications in breast augmentation: prevention and correction. *Clin Plast Surg* 28(3):587–596
- De Filippo RE, Atala A (2002) Stretch and growth: the molecular and physiologic influences of tissue expansion. *Plast Reconstr Surg* 109(7):2450–2462. <https://doi.org/10.1097/00006534-200206000-00043>
- Weck Roxo AC, Nahas FX, Salin R, de Castro CC, Aboudib JH, Marques RG (2016) Volumetric evaluation of the mammary gland and pectoralis major muscle following Subglandular and Submuscular breast augmentation [published correction appears in *Plast Reconstr Surg*, 2016 Apr;137(4):1357]. *Plast Reconstr Surg* 137(1):62–69. <https://doi.org/10.1097/PRS.0000000000001874>
- Gefen A, Dilmoney B (2007) Mechanics of the normal woman's breast. *Technol Health Care* 15(4):259–271
- Agache PG, Monneur C, Leveque JL, De Rigal J (1980) Mechanical properties and Young's modulus of human skin

- in vivo. *Arch Dermatol Res* 269(3):221–232. <https://doi.org/10.1007/BF00406415>
21. Bischoff JE, Arruda EM, Grosh K (2000) Finite element modeling of human skin using an isotropic, nonlinear elastic constitutive model. *J Biomech* 33(6):645–652. [https://doi.org/10.1016/s0021-9290\(00\)00018-x](https://doi.org/10.1016/s0021-9290(00)00018-x)
 22. Tepole AB, Ploch CJ, Wong J, Gosain AK, Kuhl E (2011) Growing skin: a computational model for skin expansion in reconstructive surgery. *J Mech Phys Solids* 59(10):2177–2190. <https://doi.org/10.1016/j.jmps.2011.05.004>
 23. Tebbetts JB, Teitelbaum S (2010) High-and extra-high-projection breast implants: potential consequences for patients. *Plast Reconstr Surg* 126(6):2150–2159. <https://doi.org/10.1097/PRS.0b013e3181f44564>
 24. Handel N (2006) Secondary mastopexy in the augmented patient: a recipe for disaster. *Plast Reconstr Surg* 118(7 Suppl):152S–167S. <https://doi.org/10.1097/01.prs.0000246106.85435.74>
 25. Siu PM, Tam EW, Teng BT et al (2009) Muscle apoptosis is induced in pressure-induced deep tissue injury. *J Appl Physiol* (1985) 107(4):1266–1275. <https://doi.org/10.1152/jappphysiol.90897.2008>
 26. Gawlitta D, Li W, Oomens CW, Baaijens FP, Bader DL, Bouten CV (2007) The relative contributions of compression and hypoxia to development of muscle tissue damage: an in vitro study. *Ann Biomed Eng* 35(2):273–284. <https://doi.org/10.1007/s10439-006-9222-5>
 27. Gur E, Hanna W, Andrighetti L, Semple JL (1998) Light and electron microscopic evaluation of the pectoralis major muscle following tissue expansion for breast reconstruction. *Plast Reconstr Surg* 102(4):1046–1051. <https://doi.org/10.1097/00006534-199809040-00019>
 28. Khavkin J, Ellis DA (2011) Aging skin: histology, physiology, and pathology. *Facial Plast Surg Clin North Am* 19(2):229–234. <https://doi.org/10.1016/j.fsc.2011.04.003>
 29. Benito-Ruiz J, de Cabo F, Manzano M, Salvador L (2019) Effects of silicone implants on the mammary gland: ultrasonographic and 3D study. *Aesthetic Plast Surg* 43(2):354–365. <https://doi.org/10.1007/s00266-018-1253-4>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.