

The Three-Dimensional Techniques in the Objective Measurement of Breast Aesthetics

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Abstract Breast symmetry, size, and shape are key components of aesthetic outcomes of augmentation mammoplasty, reduction, and reconstruction. Many have claimed that the 3D scanning technique, which measures breast volumes directly and assesses the asymmetry of the chest and breast on a 3D model, is superior to anthropometric measuring in accuracy, precision, and reproducibility. The documented methods of 3D body surface imaging include laser scanning, stereo photography and so on. To achieve ideal aesthetic results, individualized surgery planning based on a reliable virtual model of the prospective surgery outcome could be of considerable value in decision making and assisting in guidance for the surgery procedure. Additionally, the 3D scanning technique is applicable in postoperative monitoring of morphological change, notably, in a dynamic way. Another distinguishing feature is that it enables virtual division of breast volume, thus surgeons could virtually divide the breast volumes into portions using 3D scanning during the programming and evaluation of surgery plans. However, because 3D surface scanning cannot look through the breast substances and reach the interspace between the chest and posterior border of the breast/dorsal limit of the breast, the inframammary fold in larger breasts cannot be

correctly imaged, leaving the preoperative inframammary fold reference lacking. Therefore, 3D scanning is thought to be inaccurate in large and/or ptotic breasts. Another fact that prevents 3D scanning from wide application is its high cost and lack of access.

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Breast symmetry, size, and shape are key components of aesthetic outcomes of augmentation mammoplasty, reduction, and reconstruction. Many have claimed that the 3D scanning technique, which measures breast volumes directly and assesses the asymmetry of the chest and breast on a 3D model, is superior to anthropometric measuring in accuracy, precision, and reproducibility [1–4].

Up to now, objective evaluation methods have been widely applied and are developing quickly. The major function of methods is to obtain quantitative data for related parameters and, especially for non-traditional methods, to remodel the virtual visualization of postoperative breasts. However, as for the aesthetic aspect, the methods cannot yet tell the exact level of beauty. By 2011, the documented methods of 3D body surface imaging included laser scanning, stereo photography and so on. The comparison between laser scanning and stereo photography-based 3D surface imaging has been summarized in Table 1.

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Table 1 Comparison between laser scanner and stereo photography-based 3D surface imaging

3D surface imaging	Image acquisition	Advantages	Disadvantages
Laser scanning	Rays from a laser beam reflected and captured by an orientation sensitive detector[42]	Customized, dynamic, and enables virtual division of breast volume Accurate and quick [12]	Inaccurate in large and/or ptotic breasts; less accessible; does not take into account the patients' opinion of their appearance [43] The majority of the systems currently in use are bulky; data defects can occur while scanning [12]
Stereo photography	Breast capture conducted simultaneously from the right, left, front and inferior views [44]	Better reproducibility than water displacement [44]	Precision influenced by the subject-to-camera distances [44]; needs an experienced operator[44]; data processing takes up to 2 hours; the ability of the system to detect skin texture influenced by lighting conditions [45]

Features of 3D Techniques in Aesthetic Measurement of Breasts: Customized, Dynamic, and Enables Virtual Division of Breast Volume

The application of 3D techniques in the objective measurement of breasts includes 3D surface scanning and 3D model reconstruction from multi-spiral CT/MRI. Breast symmetry, size, and shape are key components of aesthetic outcomes of augmentation mammoplasty and reconstruction. To achieve ideal aesthetic results, individualized surgery planning based on a reliable virtual model of the prospective surgery outcome could be of considerable value in decision making and to assist in guidance for the surgery procedure [5]. In such cases, the breast volumetric change after mastectomy acts as a standard for surgeons to make wiser decisions on the opportune implant as well as tissue expander [6] and in determining the appropriate autologous tissue volume at the donor site with breast replica cast and other equipment [7]. In 2012, surgeons rebuilt a breast replica cast based on 3D imaging and reached better correction of breast asymmetry [8]. In the fat grafting procedures, it also makes it possible to pick out the vantage donor site by comparing the outcomes using potential anatomical sites [9]. In addition, a common virtual concept of aesthetic outcomes by 3D imaging contributes to mutual and integrated understanding between surgeons, patients, surgical material providers, and staff of medical institutes. This was put metaphorically by Gladilin and colleagues as “digital fitting room,” because the surgery provider and receiver could “try the surgery on” and even try as many styles of surgeries as he/she wants [5].

The 3D scanning technique also has its application in the postoperative monitoring of morphological change, notably, in a dynamic way. Because breast contours immediately after surgery are seldom exactly the same as the final breast shape due to postoperative edema, tissue regeneration and fibrosis around the implant, compression of the breast tissue and chest wall after implant insertion, and interaction between implants and surroundings [10], breast volume would vary for a certain period of time until

it reaches a plateau [11]. Other temporary factors include postoperative hematoma, seroma, capsular contracture, and implant leakage [7]. Thus, dynamical evaluation shows its value. By recording volume changes at each time point using a specific algorithm, it is feasible to determine the extent of soft tissue edema contribution to total breast volume change over time and obtain a common curve which provides reference for postoperative follow-up [10]. In a prospective study of breast dynamic morphological change after dual-plane augmentation mammoplasty, 3D scanning provided an objective and effective means of evaluating breast morphological changes after augmentation mammoplasty over time. It captured the slight drop in the inframammary fold by 0.5 cm throughout 11 months, thus providing evidence for choosing 6 months as the most stable observation period in the assessment of postoperative outcomes of dual-plane breast augmentation [1]. Similarly, Liu and colleagues reported an innovative algorithm to measure breast volumetric change after augmentation mammoplasty and reached better accuracy and repeatability, with half the original time (5 vs. 10 min) [7]. Moreover, Isogai and colleagues recently demonstrated an approach for superimposing images before and after surgery so that comparisons can be made constantly using three-dimensional color mapping. In their study, the authors revealed the ability to generate a numerical score based on surface deviations of one breast relative to the contralateral side. Using this method, a 5-cm elevation in the lowest point of the breast that closely matched the elevation in the point of maximal projection was identifiable. Thus, they were able to find the ideal points of breast reduction [4, 12]. Lipofilling, a reconstructive technique performed for correction of defects after oncologic breast cancer surgeries, is often related with post-injection progressive atrophy due to the deficiency of progenitors in aspirated fat tissue potentially. In a study on a novel cell-assisted lipotransfer strategy, 3D scanning was adopted for progress control before and after lipofilling until 12 months postoperative. Breast projection and breast volume were

recorded synchronously and sequential changes in the surviving fat volume were able to be shown in a curve. Thus, the researchers found that the injected adipose tissue was gradually absorbed in the first 2 months postoperatively but was minimally changed thereafter [13]. Furthermore, 3D scanning also functions in dynamic monitoring of the percentage retention after lipofilling and outcome comparison between different patient stratifications based on radiation exposure and donor site [9, 14, 15].

Another distinguishing feature over other measurement tools is that surgeons can virtually divide breast volume into portions using 3D scanning during the programming and evaluation of surgery plans. Thus, simulated breast boundary measurements could implement aesthetic outcomes predicted by a physical simulation. The transverse plane through the nipple as circumscription was initially defined by Tepper so that the breasts could be partitioned into the upper and lower portions [4, 16–18]. Tepper also showed that the ratio of the upper to lower portion is a significant parameter to measure the fullness change of the upper breast portion after plastic or reconstruction surgeries such as reduction mammoplasty. Still, they proposed “breast tissue migration” to describe the volumetric redistribution between portions over time. However, it is worth noting that the real extent of bottoming out could only be exactly objectively measured in 3D modes on the condition that the relationship between the nipple and inframammary fold is determined correctly [10]. In addition, lateral and medial portions, quadrants, and any other patterns of partitions can be obtained by 3D imaging, besides the upper and lower portions [4]. It enables the surgeon to locate particular regions that may be deemed deficient or protruding, and also serve as a guide for the injection volume required in fat grafting for accurate symmetry [4]. Gladilin and colleagues suggested using the distances between the center of the nipple and left breast border, breast lower border, and right breast border, separately to assist surgeons in locating the intended implant sites for assessment of the new inframammary fold. In the application of the three distances above, deformation of soft tissue needs to be avoided by measuring the breasts along a straight line connecting two points instead of along body contours. Plus, no pressure should be applied [5, 19].

Limitations of 3D Techniques: Inaccurate in Large and/or Ptosis Breasts and Less Accessible

Because 3D surface scanning cannot look through the breast tissue and reach the interspace between the chest and posterior border of the breast/dorsal limit of the breast, the inframammary fold in larger breasts cannot be correctly imaged, leaving the preoperative inframammary fold reference lacking [7, 20–23]. In such cases, anthropometric

assessment is mandatory as a supplement. For example, Eder and colleagues measured the distance from the nipple to inframammary fold with a measuring tape before surgery [10]. For the same reason, 3D surface scanning cannot be applied for patients with obvious ptotic breasts and other major deformities [5, 23]. When enforcing the remodeling of ptosis, it turns out that postoperative results may exhibit significant deviations from the simulation, with a more time-consuming program processing [5]. Glandular tissue may not be differentiated from soft tissue or others. Koch also pointed it out that the thorax itself or the amount of subcutaneous fatty tissue could be a source of inaccuracy [23]. Still, postoperative edema, hematoma, and the like are not easy to be differentiated from glands. That is to say, only quantitative evaluation, i.e., volume quantification, is feasible but not qualitative evaluation. The breast tissue, oil cysts, and other adjacent tissues are not likely to be distinguished through 3D surface scanning. Fortunately, these may not affect the outcome of aesthetic measurement, which depends mostly on surface appearance. However, the insensitivity to surface color, pigmentation level, or quality of skin lower its efficiency in aesthetic measurement. At the very least, this certain defect would never be avoided in traditional methods of aesthetic measurement, whether it be direct anthropometry or CT/MRI.

As mentioned above, after plastic or reconstructive surgery, the breast volume gradually declines due to detumescence, breast tissue attenuation, or to atrophy successively, before it stays steady [7]. Although dynamic measurement by 3D techniques could be of great value, patients have to be followed up for a considerable period of time through the volume diminishment period, even if a single visit is fast.

Another fact that prevents 3D scanning from wide application is its high cost [23]. Specially, laser scanning devices need to be set up very precisely using a precise geometric apparatus [24].

Comparisons Between 3D Techniques and CT/MRI

When interpreting comparisons between 3D scanning and MRI, the concept of reproducibility and exactness needs to be clarified. To be specific, a high reproducibility allows to reproduce the results with repeated measurements, even with different examiners. A high exactness indicates the precision of a technique, how much the measured volume accords with the real one. The reproducibility of MRI is valued as very good with deviations <1 %, whereas the deviation for 3D scan is 2 %. As for exactness or accuracy, MRI with a volume deviation of 2 % is superior to 3D scanning of which the deviation is 2–9 % [25]. Reproducibility could only be ponderable based on considerable exactness. Water displacement

has been frequently cited as gold standard of volumetric assessment in arm lymphedema related clinical studies and was also employed in the field of breast. Losken obtained the volume of the mastectomy specimen intraoperatively using 3D technology and compared it with water displacement on 19 breasts and found that isolated volumetric assessment would be clinically accurate 80 % of the time. On average, variability in volume measurements using 3D technology ranged from 13 to 16 % of the actual breast volume [26]. Similarly, Öhberg studied 25 subjects with lymphedema secondary to breast cancer treatment. No statistically significant result was found between the two methods although there was a tendency for the 3D-camera to overestimate the volume compared to water displacement [27]. Additionally, a more recent study on a 3D stereophotogrammetry system reported accuracy at 11.12 cc with standard error of the mean being 7.74 cc compared to water displacement [28]. Overall, the exactness in circumferential and volumetric measurements of 3D scanning is reassuring although the current studies mainly concentrate on reproducibility.

Koch and colleagues performed 3D body surface imaging to see how well 3D body surface-measured breast volume could predict MRI-measured volume in 2011. The results turned out that the 3D-measured volumes were significantly smaller than those measured with MRI. The eminent difference is believed to come from the measuring position. During an MRI scan, the patient is in a prone position so that the processus axillaris is shifted to the front and potentially added to the breast, whereas in a 3D scan, the patient is in upright position, which is more similar to the routine scenarios [4, 29–31]. Despite the notable differences in values, the results change in parallel. That is, the 3D surface-measured volume is capable of predicting the MRI breast volume using linear regression models ($R^2 = 0.59\text{--}0.77$) [20], although MRI volumetry is thought to be preferable when considering exact volume evaluation, ascribable to the higher exactness [32].

In the measuring procedure, 3D technology has distinguished advantages over CT/MRI. First, the recording time of the 3D-measurement was significantly shorter than the MRI [23]. 3D body scanning is performed in a few seconds, whereas the time required for CT/MRI (an average of 10 min/breast for merely data analysis) prevents it from being routinely applied in breast monitoring. Therefore, 3D scanning is superior to MRI in longitudinal observations [5, 32]. Second, a 3D scan is free of adverse health effects, from which patients carrying metal equipment such as a heart valve could benefit [5]. Third, compared with CT measurement, the 3D technique is non-invasive and eliminates X-ray exposure for patients and more importantly, medical personnel [33–40], although high-resolution CT provides an excellent presentation of anatomic structure which is less valuable information concerning aesthetic measurement.

Recent Updates and Prospects in 3D Measurement Systems

While mainstream 3D techniques are becoming robust, frontier practices keep emerging. An open source online solution of using photographs from smartphones for 3D imaging, Autodesk 123d Catch[®], was introduced in 2014 by Koban. [41]. The App showed good accuracy of the 3D reconstruction for a standard mannequin model but the capture time was prolonged. Although errors still existed, it provided inspiration on the development of 3D systems based on mobile devices, which might make aesthetic evaluation portable and more accessible. The currently available systems include Axis3, 3dMD, and Vectra [25].

Conclusion

Three-dimensional techniques measure breast volumes objectively and assess the asymmetry, and are notably superior to traditional anthropometric measuring in accuracy, precision, and reproducibility. The reliable virtual model of the prospective surgery outcome generated through 3D system functions is valuable in decision making during plastic procedures. Additionally, 3D techniques also have application in dynamic monitoring of morphological change, which allows for quantitative progress control after lipofilling. Despite the features, 3D scanning is thought to be inaccurate in large and/or ptotic breasts. Another fact that prevents 3D scanning from wide application is its high cost and lack of access.

At present, ongoing development of novel and frontier approaches such as online and portable solutions is exciting. In the future, guidance with a high level of evidence is in demand to provide counseling for clinical decision making toward customized optimum options for better aesthetic outcomes.

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Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflicts of interest to disclose.

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