Correlation of centroid-based breast size, surface-based breast volume, and asymmetry-score-based breast symmetry in three-dimensional breast shape analysis

Korrelation von Centroid-basierter Brustgröße, oberflächenbasiertem Brustvolumen und Asymmetrie-Score-basierter Symmetrie bei der dreidimensionalen Brustform-Analyse

Abstract

Objective: The aim of this study was to investigate correlations among the size, volume, and symmetry of the female breast after reconstruction based on previously published data.

Methods: The centroid, namely the geometric center of a three-dimensional (3D) breast-landmark-based configuration, was used to calculate the size of the breast. The surface data of the 3D breast images were used to measure the volume. Breast symmetry was assessed by the Procrustes analysis method, which is based on the 3D coordinates of the breast landmarks to produce an asymmetry score. The relationship among the three measurements was investigated. For this purpose, the data of 44 patients who underwent unilateral breast reconstruction with an extended latissimus dorsi flap were analyzed. The breast was captured by a validated 3D imaging system using multiple cameras. Four landmarks on each breast and two landmarks marking the midline were used.

Results: There was a significant positive correlation between the centroid-based breast size of the unreconstructed breast and the measured asymmetry (p=0.024; correlation coefficient, 0.34). There was also a significant relationship between the surface-based breast volume of the unaffected side and the overall asymmetry score (p<0.001; correlation coefficient, 0.556). An increase in size and especially in volume of the unreconstructed breast correlated positively with an increase in breast asymmetry in a linear relationship.

Conclusions: In breast shape analysis, the use of more detailed surface-based data should be preferred to centroid-based size data. As the breast size increases, the latissimus dorsi flap for unilateral breast reconstruction increasingly falls short in terms of matching the healthy breast in a linear relationship. Other reconstructive options should be considered for larger breasts. Generally plastic surgeons should view the two breasts as a single unit when assessing breast aesthetics and not view each breast on its own.

Keywords: three-dimensional, breast shape analysis, correlation, centroid size, surface-based volume, symmetry analysis

Zusammenfassung

Ziel: Das Ziel der Studie war es, die Korrelation zwischen der Größe, dem Volumen und der Symmetrie der weiblichen Brust nach Rekonstruktion, basierend auf vormalig publizierten Daten, zu untersuchen.

Methode: Der Centroid, das geometrische Zentrum einer auf dreidimensionalen (3D) Brust-Landmarken basierenden Konfiguration, wurde zur Kalkulation der Größe der Brust verwendet. Die Oberflächendaten der 3D-Brustbilder wurden benutzt, um das Volumen zu messen. Die

Ergebnisse: Es ergab sich eine signifikant positive Korrelation zwischen der Centroid-basierten Brustgröße der unrekonstruierten Brust und der gemessenen Asymmetrie (p=0.024; Korrelations-Koeffizient, 0.34). Es ergab sich ebenfalls eine signifikante Beziehung zwischen dem Oberflächen-basierten Brustvolumen der nicht betroffenen Seite und dem Asymmetrie Score insgesamt (p<0.001; Korrelations-Koeffizient, 0.556). Eine Zunahme der Größe und mehr noch des Volumens der unrekonstruierten Brust korrelierte positiv mit einer Zunahme der Brust-Asymmetrie in einem linearen Zusammenhang.


In weiterführender Betrachtung sollten plastische Chirurgen bei der Untersuchung des ästhetischen Aussehens der Brust die Brust als Gesamtheit betrachten und nicht jede Brust für sich alleine ansehen.

Schlüsselwörter: dreidimensional, Brustform-Analyse, Korrelation, Centroid-Größe, oberflächenbasiertes Volumen, Symmetrie-Analyse

Introduction

Objective evaluation of the correlation among breast size, volume, and symmetry in three-dimensional (3D) breast assessment using a multiple camera system is a new concept. No standardized method for shape analysis of the female breast is currently available, although different approaches have been attempted [1]. Modern methods are commonly based on recording breast morphology in three dimensions before shape analysis is conducted. Several capture systems have been developed. Multiple-camera stereophotogrammetry relies on the simultaneous capture of an image using several digital cameras linked to a computer system to obtain 3D visual information [2]. The linking of any two cameras as one pod resembling natural conditions of human vision has been previously described [3], [4]. Knowledge of the different views of an object in each eye has been applied to present-day clinical treatment [2], [5]. The application of several camera pods in 3D breast assessment has been reported, and the results of breast reconstruction using the unilateral extended latissimus dorsi flap after mastectomy have been described [6]. An algorithm was developed for breast volume and shape measurements, and the differences between the right and the left sides were calculated. The reconstructed breast was found to be smaller in size than the opposite side [6]. An objective qualitative and quantitative assessment was achieved.

The ultimate goal of breast reconstruction after unilateral mastectomy is to restore the breast shape and size and maximize the symmetry between the operated side and the unaffected breast. However, whether the size and volume of the native, unreconstructed breast impacts the overall desired symmetry following reconstruction remains unknown. The availability of reliable methods with which to measure breast size, volume, and symmetry [1], [6], [7], [8] facilitates investigation of the effects of these variables on the overall breast symmetry following reconstruction. In contrast to unreliable methods of subjective breast assessments objective methods are frequently based on mathematical calculations [9]. Shape analysis is not only a complex subject, but a growing branch of statistics [10]. The translational description of the concurrent statistical methods to a medical public in simple terms has been attempted before, however remains a challenge [11]. One way forward is to simplify the shape of interest to simple distances of the object that can be obtained between landmarks. Landmarks are anatomical points that stand out on bony or soft tissue structures and that are very useful in objective shape analysis [11]. Several distances between landmarks that form a landmark configuration can represent the simplified shape of the object and can be used to calculate the
centroïd, the geometrical center of this configuration. The result of this calculation reveals a figure that gives a feel for the size of the object of interest. After further development in recent times statistical shape analysis was applied to assess the full geometry of the object [10]. For this purpose surfaces were analysed that were made up of many triangles in a triangulated mesh by three-dimensional imaging method [11] and volumes were obtained by calculating a back wall by software interpolation to close these surfaces. After mathematical calculation figures representing either the two dimensional surfaces or the three-dimensional volumes were obtained and offered the option to be used in objective breast assessments. The later can be conducted in a more simple centroïd-based or in a more complex surface/volume-based way and both methods are here presented and correlated to breast symmetry.

**Aim of study**

The aim of this study was to evaluate the correlation of two different methods investigating the size and volume with the symmetry of the female breast after unilateral reconstruction with the latissimus dorsi flap.

**Method**

First, we used the centroïd, namely the geometric center of the 3D breast landmark-based configuration, to calculate the breast size [6]. The distances from each landmark to this point, the geometric center, were measured and squared (²) to reduce possible skewness. The centroïd size was calculated as the square root of the sum of the squared Euclidian distances from the landmarks to the centroïd. Data for the centroïd size were documented on a meter scale. Second, for volume assessment a surface measurement-based method was applied [12]. By software calculation with BAT software the surface of the breast segment was given and data were documented on a squared meter scale. A back wall was then computed and the three-dimensional volume of this breast segment provided. Third, a calculation based on Procrustes analysis was used to produce a breast asymmetry score [11]. For breast asymmetry analysis a mirror image reflection of the 3D landmark configuration was obtained. This enabled superimposition of the original landmark configuration onto the reflected one. Procrustes analysis provided an asymmetry score which was obtained when all landmarks were logged in a (k×m) matrix X by a software called R, in which k equaled 10 landmarks, four on each breast and two for the midline, multiplied with m, which equaled the three dimensions of measurements (x, y, z). Therefore three different methods were used for objective breast assessment and comparison was conducted between the correlation of the centroïd-size-based calculation and the symmetry and the volume-based calculation and the symmetry of the breast. The magnitude of the correlation of the size of the breast with the asymmetry score as well as the magnitude of the correlation of the breast volume with the asymmetry score was examined by calculating the correlation coefficient. This offered the option of comparison of the two methods of shape analysis, the centroïd-based and the volume-based one. Data collection relied on the use of a validated prototype 3D capture system based on stereophotogrammetry, which comprised eight digital cameras for 3D breast capture (Figure 1) [12]. The system, named multiple stereophotogrammetry system, was developed in a conjoint project between computer scientists, statisticians and clinicians for research purposes and patient capture but not for commercial use. Breast analysis tool software (BAT) was used for image processing. Standardisation of image capture was developed in a research project by help of a positioning frame in which the patient could stand on a standing step and bend forward with the upper body while leaning against a hip roll and stretching out the arms so that the breast lifted off the chest-wall and a complete view of her breast, also from underneath, was achieved [6]. The analysis was based on the previously reported findings of 44 patients who had undergone immediate unilateral breast reconstruction using solely an extended latissimus dorsi flap [6]. The study group was assessed retrospectively and comprised of a group of women having all undergone the same type of breast reconstruction. Demographic data to age, body mass index, parity, chest wall size and bra cup size were obtained. The operation included a reconstruction by a pedicled latissimus dorsi flap with local fat tissue around the muscle but no additional implant insertion. Further, no contralateral surgery was conducted. The operation was conducted by six different consultant plastic surgeons with specialization in breast surgery. Three-dimensional images of the breasts were retrieved (Figure 2, Figure 3, Figure 4), and the 3D landmark configurations of four landmarks on each breast and two landmarks marking the midline were digitized by the examiner [6].

**Results**

There was a statistically significant positive correlation between the centroïd-based breast size, and the asymmetry score (p=0.024) with an assumed significance level of 0.05. The increase in the size of the unreconstructed breast contributed significantly to the increase in the asymmetry score (r=0.34) (Figure 5). The volume of the breast measured by surface data showed also a statistically significant relationship with breast symmetry (p<0.001); the positive correlation coefficient between volume and asymmetry was r=0.56 (Figure 6). This time the correlation was even more pronounced. The lines of “best fit” through the data revealed an upward slope, which suggested that the larger the size of the unreconstructed breast, the larger the asymmetry score. Therefore, as the size of the unreconstructed side increased, increasingly more breast asymmetry was...
Figure 1: Multiple stereophotogrammetry system

Figure 2: Three-dimensional imaging in live model
Figure 3: Breast segment displayed with triangulated mesh

Figure 4: Breast segment displayed with shaded surface
Figure 5: Correlation between centroid size and asymmetry score

Figure 6: Correlation between volume and asymmetry score
evident in a linear relationship. This was true for both the centroid-size-based calculations and the volume-based calculation based on surface data. Regarding the demographic data twelve patients were under and thirty-two over fifty years of age. Twenty-three had a body mass index of under/equal 25 and twenty-one of over 25. The distribution of parity revealed that nine ladies had no children, ten had one child, fifteen had two children and ten had three or more children. The chestwall size was in thirty-three cases smaller or equal 36 (≈75–80 cm) and in eleven cases more than 36. A bra cup size of A or B was given by fourteen and one of more than B by thirty ladies. From these above mentioned factors the body mass index was solely linked to breast asymmetry, which had a greater extent in the larger women. The extended latissimus dorsi flap for unilateral reconstruction after mastectomy was not sufficient to achieve symmetry, and asymmetry increased continuously in increasingly larger breasts.

Discussion

The term “centroid size” is used in morphometrics and, refers to the quantitative analysis of the form or shape of an object. Length, width, and surface measurements provide a multitude of data for shape analysis, many of which are correlated with one another; however, only few present independent variables. In shape analysis, relative data are usually of more interest than absolute figures [12], [14]. Therefore, calculation of the centroid size in isolation does not provide as much information as calculation of the overall breast symmetry. When conducting this study, the question arose whether to look at both breasts as a whole when examining the breast appearance/aesthetics or to judge each breast on its own. The herein presented shape analysis clarified that viewing each breast on its own would be less effective. Symmetry is an important factor in breast aesthetics and must include both breasts as two parts of a whole. In clinical practice, plastic surgeons should view the two breasts as a single unit when assessing breast aesthetics and not view each breast on its own. While this is not a direct conclusion from this study comparing two methods of shape analysis on reflective consideration any other approach could not be recommended. The mathematical calculation for centroid size was based on four landmark coordinates in the present study. Landmarks are well-defined anatomical points that represent bony or soft tissue prominences of the structure of interest. Finding enough data to describe the shape of an object of interest, which in this case was the female breast, can be difficult to achieve because these data must be consistent in all analyzed individuals. In the current paper the centroid size investigation was one way to investigate the breast. The other approach was the surface-volume-based investigation. Importantly, it has to be clarified that the two methods follow a different approach and can be compared to each other. The surface-volume-based investigation goes beyond the mere comparison of the data of a limited amount of a handful, consistent landmarks. Our detailed analysis of the correlation among size, volume, and symmetry showed that volume-based breast calculations relied on a multitude of data in the form of a surface mesh versus centroid-based measurements of breast size, which only relied on the 3D coordinates of four landmarks on each breast. Consequently, breast volume-based breast calculations were considered to be more exact and therefore more meaningful and preferable. Both objective measurement methods though relied on the input of computer scientists developing software for analysis and statisticians providing asymmetry score calculations. This is a difficulty in objective breast analysis, that due to the complexity of the breast shape supportive services are required. While simple linear measurements with a tape measure provide some limited objective data to surgeons, which they can collect fully on their own, the processing of three-dimensional data of four landmarks, that are representing a very simplified display of the female breast configuration, requires interdisciplinary support for the analysis and consequently costly and partly cumbersome software calculations. Even more though this is true for the more complex shape analysis based on multiple surface data obtained by hundreds of little triangles from a triangular shape mesh or even further additional software interpolation of a back wall to close the space and to provide breast volume. While the more complex surface/volume analysis should be closer to the true shape features and therefore appears preferable, the less complex analysis of a few landmarks might be sufficient for some questions to be investigated. As a whole any shape analysis is only truly meaningful if it looks at the breast as a unit, as otherwise no information to symmetry can be provided and therefore any conclusions that might be drawn from the comparison of the correlation of the two methods with symmetry are disabled. A perfectly symmetric breast would exactly match its mirror image and have an asymmetry score of zero. Every mismatch contributes to the asymmetry score; the higher the asymmetry score, the poorer the breast symmetry. Application of 3D imaging by multiple cameras based on stereophotogrammetry in women with larger breasts is new, and few studies have been published in this field to date [6]. Data assessments involve cumbersome specialized statistical calculations; however, the results provide objective data that can be used for comparison studies. Future data assessments will involve automated software calculations in future user-friendly applications. The explanation of some parts of the specialized statistical calculations [10] have been conducted before. The goal should be to make the subject more comprehensive to the general plastic surgical public [11]. Based on clinical experience, plastic surgeons recognize that with increasing breast sizes, the unilateral latissimus dorsi flap for breast reconstruction after mastectomy may not lead to a satisfactory degree of overall breast symmetry. However, objective proof of this is still lacking.
Calculation of the correlation coefficient showed that increases in the asymmetry score were associated with larger breast sizes. In practical terms, we found a linear relationship between increasing breast sizes and asymmetry; the reconstructed breast remained too small to match the healthy side in size and shape with increasingly larger sizes. Therefore, other methods of reconstruction should be considered. Especially the linear relationship of continuously increasing breast asymmetry with increasing breast sizes in this reconstruction with the latissimus dorsi flap was meant to be objectively demonstrated in this publication. The question naturally arises what possible alternative options of reconstructions could be thought of, however this was not the subject of this study. The here presented study was conducted retrospectively to objectively assess the outcome after breast reconstruction and demonstrate the results. Based on the findings discussions nevertheless can be conducted to prefer different methods of breast reconstructions in larger women, however other methods were not compared in this study. Other aspects such as patient satisfaction and choices to undergo further or contralateral surgery would require a different investigation. In the future more prospective studies might be possible to improve surgical planning and postoperative outcomes especially when three-dimensional capture systems will develop to be less costly, cumbersome, time consuming and more easy to use than they have been. As soon as these issues will have improved and smaller, even portable systems have been refined more objective comparative studies of surgical techniques should be possible. Prior to the clinical application of 3D imaging, investigations of the accuracy and reproducibility of this method have demonstrated the reproducibility of the measurements in plaster and live models [8], [12], [13]. The concept of mirror imaging of one breast with the other was applied to determine the asymmetry score. Mirror imaging in shape analysis is well established in facial surgery [15]. However, its application in the field of breast analysis is new. One way to assess breast symmetry is to evaluate whether the reconstructed side matches the shape and size of the breast before mastectomy. However, because of the retrospective nature of this study, we chose to compare the reconstructed breast with the unreconstructed opposite side. We acknowledge that this technique is an indirect comparison of variables; nevertheless, we were able to successfully quantify the degree of achieved breast symmetry. Limitations of the current study include lack of a comprehensive analysis of additional variables that may contribute to breast symmetry, including the effects of radiation or thoraco-dorsal neurotomy, age, BMI, parity, chest wall size, and cup size. Previously published data showed that a significant effect was only found for BMI and breast asymmetry (p=0.004) [6]. A BMI of <25 kg/m² was associated with an asymmetry score of 43.64, and a BMI of >25 kg/m² was associated with an asymmetry score of 61.99, the latter indicating lesser symmetry. The brassiere cup size, which is recorded on admission, was previously found not to have a significant effect on breast symmetry (p=0.062) [6]. In spite of the challenges objective breast assessment still faces there are many possible applications that are worth the effort. Among these are the establishment of the eligibility of patients for certain breast operations at the cost of the public, the objective proof regarding asymmetries in augmentation or reduction cases, the support in disputes with colleges, patients or even legal representatives regarding the surgical result, the planning of implant sizes at the outpatient department, the support this method could pose to younger and less experienced surgeons, the options to evaluate how closely the surgical objective has been met by the result and finally the application in the frame of hospital certifications and audits for purposes of modern quality control in the health sector.

**Conclusion**

In breast shape analysis, the use of more detailed surface data should be preferred to centroid-based data. Increases in size and especially volume of the unreconstructed breast correlated positively with increases in breast asymmetry. This correlation of an increase in the breast asymmetry score with an increase in breast size and volume objectively proves that the unilateral latissimus dorsi flap for breast reconstruction after mastectomy does not achieve symmetry in increasingly larger breasts in a linear relationship. Larger breasts are more difficult to reconstruct when aiming for symmetry using only the latissimus dorsi flap, and other or additional methods of reconstruction should be considered. Generally plastic surgeons should view the two breasts as a single unit when assessing breast aesthetics and not view each breast on its own.

**Notes**

**Evidence**

Evidence level: III

**Competing interests**

The authors declare that they have no competing interests.

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Ethical approval

Ethical approval was obtained from the local ethics committee. Patient confidentiality was maintained.

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Corresponding author:
Helga Henseler, M.D., Ph.D.
Medizinische Hochschule Hannover, Klinik für Plastische, Hand- und Wiederherstellungschirurgie, Carl-Neuberg-Straße 1, 30625 Hannover, Germany,
Mobile: 0049 152 0944 0311, Phone: 0049 511 532 8864, Fax: 0049 511 532 8890
henseler.helga@mh-hannover.de

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