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The current gold standard breast volumetry technique seems to overestimate fat graft volume retention in the breast: A validation study[☆]

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Summary *Background:* MRI is generally considered as the gold standard for measuring breast volume because of its high accuracy of the modality. Many techniques used to measure total breast volume have been validated, but none of these techniques have been validated for their ability to measure the volume retention of fat grafts in the breast. In this study, the authors investigated the accuracy of the most common MRI technique used to measure fat graft retention in the breast by measuring the volume changes after breast augmentation.
Methods: Patients undergoing breast augmentation with either breast implants or fat grafting underwent MRI scans before and after surgery. Blinded observers measured the change in breast volume from the MRI scans. The difference between the measured change in breast volume and the volume of the breast augmentation was used to determine the accuracy of the MRI technique.
Results: Twenty-eight patients with a total of 56 breasts were included. In total, 168 measurements of change in breast volume were performed by the observers. The MRI measurements of change in breast volume overestimated the true volumes of the breast augmentations by

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an average of 50.8%, and only 8 of the 168 individual measurements had measurement errors below 50 mL.

Conclusion: The MRI technique, which is considered as the gold standard for the quantification of fat graft volume retention, was associated with a significant measurement error. These findings have potential implications for the interpretation of previously published results of studies based on this technique.

Background

When fat grafting is performed, it is expected that a portion of the fat graft undergoes resorption after surgery.[1-3] Therefore, studies investigating fat grafting often involve measurement of the fat graft volume retention (i.e., what percentage of the graft volume will remain after the resorption process has ended). We hypothesize that the current method used to measure fat graft volume retention in the breast with MRI may be associated with a much larger error than that previously estimated.[4]

The typical procedure used to assess fat graft volume retention in the breast is as follows[5-10]: (1) the total breast volume is measured by MRI before surgery and again after surgery when no further resorption is expected; (2) the preoperative breast volume is subtracted from the postoperative breast volume to calculate the *change* in the breast volume; and (3) the change in the breast volume is divided by the injected fat volume to calculate the volume retention of the fat graft.

For example, if a breast is augmented with a 200 mL fat graft and we measure the preoperative breast volume as 300 mL, then the breast volume one year after fat grafting is 400 mL. The difference between the two measurements is a 100 mL increase in breast volume. The change in volume is then compared to the injected volume of 200 mL, which is interpreted as a fat graft volume retention rate of 50%.

The validity of the approach described above hinges on the presumption that the measured difference in breast volume is identical to the residual volume of the fat graft (i.e., a 300 mL breast plus a 100 mL residual fat graft volume will result in a 400 mL breast). The accuracy of simply subtracting the measurements of the total breast volume to calculate the change in breast volume (e.g., after breast augmentation) has never been convincingly validated.

In this study, we investigated the accuracy of the most commonly used technique to measure fat graft volume retention with MRI scans, which has been described by Herold et al.[5-8] We investigated the efficiency of the MRI technique to measure the change in breast volume after breast augmentation with either breast implants or fat grafts. The agreement between the measured change in breast volume and the true volume of the breast augmentation (i.e., the volume of the breast implant or fat graft) is used to determine the accuracy of the technique.

Patients and methods

The collection of data was approved by the regional Danish Data Protection Agency, and the need for study approval was waived by the Regional Committee on Health Research Ethics. All patients provided written informed consent before participating in the study.

Patients

Patients who were scheduled for bilateral cosmetic breast augmentation with either breast implants or fat grafting were eligible for inclusion in the study. The exclusion criteria were any known breast disease, pregnancy, or contraindications for MRI. Patients were recruited from June 2014 to April 2017 at the Copenhagen University Hospital, Rigshospitalet and Amalieklinikken, Copenhagen. Patients who received breast implants underwent their first MRI examination within 10 days before surgery and the second MRI examination after a minimum of four months, at which time the postoperative edema was expected to have subsided. Patients were examined at the same time during their menstrual cycle to prevent cyclical breast volume changes from influencing the measurements. The patients who underwent fat grafting were examined on the day before surgery and again within three hours after surgery, at which time no fat graft resorption was expected, and minimal postoperative edema would have formed.

MRI examinations

Patients were examined with a 3-Tesla MRI unit (Siemens Magnetom Verio; Erlangen, Germany), except for two patients who were examined with a 1.5-Tesla unit (Siemens Magnetom Avanto; Erlangen, Germany) because of the maintenance of the 3 Tesla unit. A 4-channel breast coil was used in all examinations. Volume assessments were performed on an axial breathhold DIXON sequence, with 72 slices and a 3-mm slice thickness. Patients were examined head-first, with their arms raised and in the prone position, and with the breasts freely suspended in the breast coil.

MRI volume assessment

All volume assessments were performed by three independent observers (JH, MNH, and SS) who were blinded to the true volume of the breast augmentation (i.e., implant size and fat grafting volume).

The total breast volume was measured by delineating the breasts on the axial slices, as described by Herold et al.[5-8] The borders are shown in Figure 1. The skin was used as the superficial border, and the internal costal surface was used

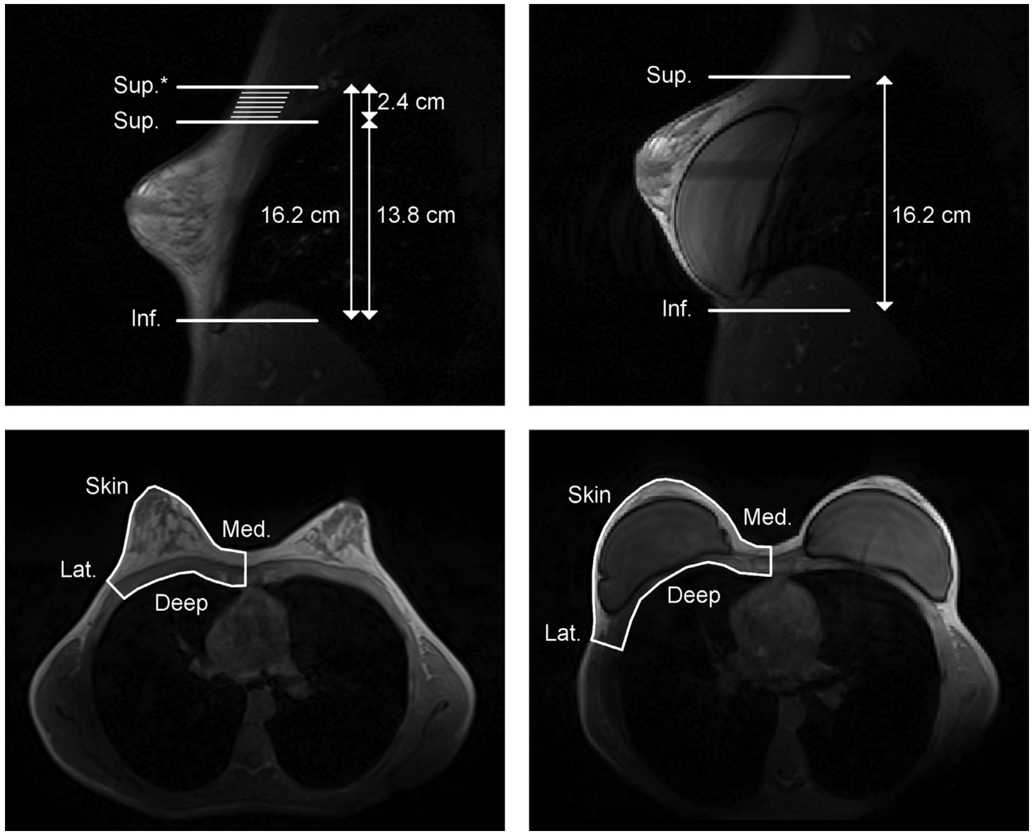

Figure 1 Sagittal and transverse views of the preoperative (left) and postoperative MRI examinations (right) of a patient with breast implants. Sup.* indicates the adjusted cranial border of the preoperative breast, and the hatched area represents the extra tissue added to obtain an equal number of slices on the two examinations. *Sup.*: superior; *Inf.*: inferior; *Lat.*: lateral; Med.: medial.

as the deep border. The center of the sternum was used as the medial border, and the lateral border was placed at the point where the thickness of the breast was equal to the thickness of the surrounding skin. Similarly, the cranial and caudal borders of the breast were placed, where the subcutaneous thickness of the breast was equal to the thickness of the skin identified on sagittal view. The change in breast volume after breast augmentation was calculated by subtracting the preoperative breast volume from the postoperative breast volume. All of the above-mentioned steps were verified by Dr. Herold, who was the corresponding author of the most commonly used MRI technique.[7] Dr. Herold added an additional step to the procedure, which was to include an equal number of slices in the preoperative examination and the postoperative examination. This procedure was performed by adding extra slices to the preoperative scan (because the breast was smaller before the augmentation). The delineation along with the procedure for adding extra slices to the preoperative scan is shown in Figure 1.

To determine the intraobserver variation, the volume measurement was repeated by each observer for 12 patients (six patients with implants and six patients with fat grafting).

The volumes of the breast implants were also measured by delineating the implants directly on the postoperative MRI examination. The measured volume of the implant was compared to the size of the implant stated by the manufacturer to provide a control for the MRI delineation accuracy.

Data analysis

The measurement error was calculated by subtracting the true volume of the breast augmentation (i.e., the implant size or fat graft volume) from the measured change in breast volume between the preoperative and postoperative MRI examinations:

$$\begin{aligned} \textit{Measurement error} = (&\textit{postoperative MRI measurement} \\ &-\textit{preoperative MRI measurement}) \\ &-\textit{true volume} \end{aligned}$$

The percentage of measurement error was calculated by dividing the volume of the measurement error by the true volume of the breast augmentation. The measurement errors were then categorized into three sets of clinically relevant margins of error chosen a priori: 1) less than 50 mL, 2) between 50 and 100 mL, and 3) more than 100 mL.

Statistical analyses

The sample size was calculated using the Clopper-Pearson exact method, which resulted in at least 53 breast augmentations. We targeted a 1:1 ratio between breast augmentations with implants and those with fat grafting. A scatterplot was used to visualize the distribution of measurement errors against the true volume of the breast augmentations. A simple linear regression fitted through zero and a paired *t*-test were used to assess the accuracy of the measured change in the breast volume compared to the true volume of the breast augmentation. All analyses were performed using R statistical software, version 3.3.3 (www.r-project.org), and the p-values were evaluated at a 5% significance level. All plots were constructed using GraphPad Prism version 7.02 (GraphPad Software, California, USA, www.graphpad.com).

Results

Patients

Twenty-eight patients who underwent bilateral breast augmentation (56 breasts) were included in the study. Fourteen patients underwent breast augmentation with implants, and 14 patients underwent breast augmentation with fat grafting. Patient characteristics and measurement errors are summarized in Table 1. The patients who received implants underwent the second MRI examination after 4.5 months (range: 4–7 months), and all patients who received fat grafting underwent the second MRI examination within three hours after surgery. Patients who received implants had a mean weight gain of 0.54 kg (95% CI −0.3-1.4 kg) at the time of follow-up. The change in weight was not considered for the patients who received fat grafting because the interval between the MRI examinations was less than 24 h.

MRI measurements

Three observers calculated the changes in the breast volume in all 56 breasts from 28 patients and repeated the measurements in 24 breasts. This approach provided a total of 168 individual measurements and 72 repeated measurements of the change in breast volume after breast augmentation. The average time required to measure the change in breast volume for one patient with two breasts was 183 min (95% CI 170–196 min).

Measurement error

The mean measurement error, which was defined as the difference between the measured change in the breast volume and the true volume of the breast augmentation, was 178.4 mL (95% CI 156–201 mL) among the breast implant patients and 153.4 mL (95% CI 138.4–168.5 mL) among the fat grafting patients. These measurement errors correspond to percentage errors of 50.8% (95% CI 45.3%—56.3%) in the implant patients and 50.9% (95% CI 45.7%—56.0%) in the fat grafting patients. When the measurement errors were categorized into clinically relevant margins of error, only 8 of the 168 individual measurement errors (4.8%) were less than 50 mL. Thirty of the 168 measurement errors (17.9%) were between 50 and 100 mL, and 130 measurement errors (77.4%) were greater than 100 mL.

A scatterplot of the measurement errors against the true volumes of the breast augmentation is presented in Figure 2, which shows that 166 of the 168 measured changes

Table 1 Patient characteristics and measurement errors.

Breast augmentation with implants	
Age, yr	28.2
Range	21-39
Weight, kg	57.9
Range	47.5-68
BMI	21.1
Range	18.5-26.2
Implant volume, mL	349
Range	225-420
Measurement error, mL	178.4
95% CI	155.8-201.0
Percentage error, %	50.8
95% CI	45.3-56.3
Breast augmentation with fat grafting	
Age, yr	34.9
Range	30-44
Weight, kg	69.5
Range	59-83
BMI	24.2
Range	22.1-26.8
Fat graft volume, mL	304
Range	250-350
Measurement error, mL	153.4
95% CI	138.4-168.5
Percentage error, %	50.9
95% CI	45.7-56.0
Measured change in breast volume - overall	
Individual measurements, No.	168
Repeated measurements, No.	72
Measurement error, mL	165.9
95% CI	152.2-179.6
Percentage error, %	50.8
95% CI	47.0-54.6
Measurement error, No. (%)	
<50 mL	8/168 (4.8)
50-100 mL	30/168 (17.9)
>100 mL	130/168 (77.4)
Interobserver variation, mL	55.25
95% CI	47.1-63.4
Percentage variation, %	16.4
95% CI	14.1-18.6
Intraobserver variation, mL	19.77
95% CI	15.9-23.7
Percentage variation, %	6.0
95% CI	4.8-7.3
Volume measurement of the implant by direct delineation on MRI examination	
Implants, No	28
Measurement error, mL	15.52
95% CI	9.8-21.2
Percentage error, %	4.4
95% CI	2.9-5.9
Systematic measurement error, mL	−6.72
95% CI	−14.3 to 1.0
Systematic measurement error, %	−1.78
95% CI	−3.9 to 0.34

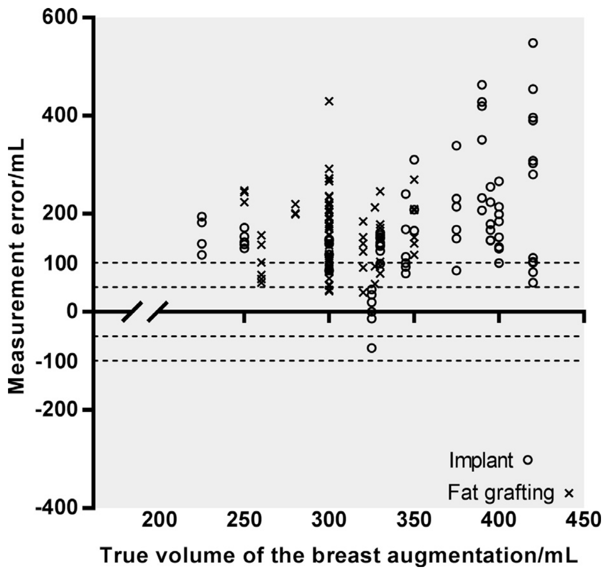

Figure 2 Scatterplot of the measurement error against the true volume of breast augmentation. Measurements close to the true volume are located near the horizontal axis, and the dotted lines show the clinically relevant margins of error for the 50 mL and 100 mL categories. All but two of the 168 measurements overestimated the true volume of the breast augmentation.

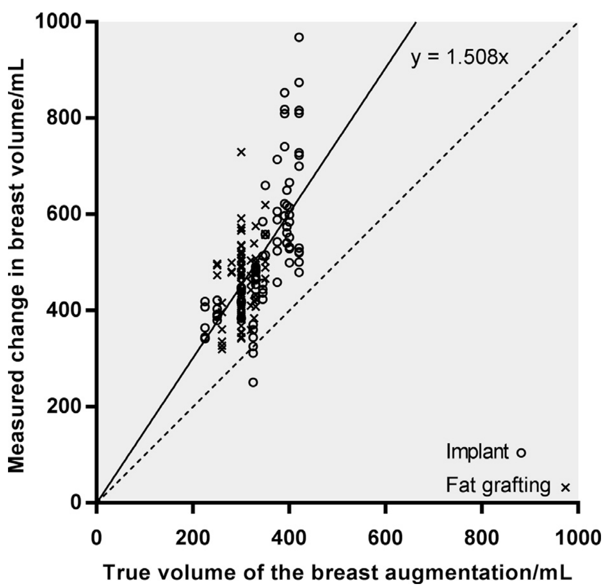

Figure 3 Linear regression showing the relationship between the measured change in breast volume and the true volume of the breast augmentation. The dashed line indicates no measurement error. The regression line has a slope of 1.508.

in breast volume overestimated the true volume of the breast augmentation. The relationship between the measured changes in breast volume and the true volume of the breast augmentation is shown in Figure 3 with a simple linear regression. The slope of the regression line indicates that the measured change in breast volume tended to overestimate the true volume of the breast augmentation by 50.8% ($p < 0.001$). The magnitude of the measurement error increased with larger breast augmentation, but the percentage measurement error (of the true volume of the breast augmentation) did not significantly depend on the true volume of the breast augmentation or on whether the augmentation was performed with implants or fat grafting.

Interobserver and intraobserver variations

The mean difference in the measured change in breast volume among the three observers ($n = 168$) was 55.25 mL (95% CI 47.13–63.37 mL, range 0.28–268.23 mL). The mean difference between repeated measurements of the change in breast volume performed by the same observer ($n = 72$) was 19.77 mL (95% CI 15.87–23.67 mL, range 0.05–75.80 mL).

Volume measurement of the implant by direct delineation on the MRI examination

To test the accuracy of the MRI unit and a straightforward delineation, we measured the volumes of the breast implants directly on the postoperative MRI examinations ($n = 28$). The mean measurement error of implant volume compared to the volume stated by the manufacturer was 15.52 mL (95% CI 9.8–21.2), corresponding to a percentage measurement error of 4.4% (95% CI 2.9–5.9%). The systematic error was negligible at −1.8% of the implant volume (not statistically significant).

Discussion

MRI is probably the most accurate technique used for the noninvasive measurement of tissue volume, and therefore, MRI is considered the gold standard in breast volumetry.[6] The use of MRI as an accurate imaging modality is supported in our study by the low measurement errors, and the absence of a systematic error, when using MRI to measure the total implant volume by direct delineation on the MRI scan. Nonetheless, our findings show that the current technique used to analyze MRI scans to measure the *change* in the breast volume grossly overestimated the expected volume increase after breast augmentations. In our view, the problem is not due to a lack of accuracy in the MRI scans or with measuring the total breast volume, which has been demonstrated to be fairly accurate using MRI, 3D imaging, or CT scans.[11-15] However, it seems that the current technique used to measure the *change* in the breast volume with multiple MRI scans does not measure what is intended to be measured: The current technique of using MRI scans to calculate change in breast volume relies on a presumption that a 300 mL total breast volume plus a 100 mL breast augmentation will result in a 400 mL total breast volume. Our results suggest that the use of the current MRI technique to measure change in breast volume after transferring volume will significantly overestimate the actual transferred volume (e.g., the volume of a residual fat graft).

We hypothesize that the systematic overestimation found in our study is due to physical changes in the dimensions of the breast that occur when the volume changes as follows: A breast undergoing a volume increase will do so by adding projection anteriorly and also by expansion of the breast borders. The inferior border will be moved downward, the lateral border will be moved more lateral, and the superior border will be moved more upward. Therefore, the measured change in breast volume is the sum of both the transferred tissue (e.g., the breast implant or the fat graft) *and* the tissue surrounding the pre-enlarged breast that will become a part of the breast when the borders expand. We have proposed this principle previously,[4] and it is supported by the results of this study. The current MRI technique, pioneered by Dr. Herold et al. [5] is very accurate in determining total breast volume, but the technique is not appropriate for tracking the volume retention of fat grafts in the breast. A fat graft in the breast is usually dispersed as much as possible during surgery, and therefore, it cannot be directly delineated, instead it has to be determined by measuring the change in breast volume.[16,17] The solution for measuring fat graft volume retention (i.e., the percentage volume of a fat graft that remains after the resorption period) will be to further develop the MRI technique to measure changes in the breast volume that correspond to the change in the fat graft volume.

Limitations

The potential limitations of this study should be addressed. First, there is a possibility that the technique was used incorrectly in this study. To ensure the correct use of the technique, all three observers were individually trained in following all steps of the procedure, as described in the Methods section. Many steps require subjective decision making by the observer, which is a likely explanation for the relatively high interobserver variation (55.25 mL, 95% CI 47.13–61.98 mL), but it does not account for the much higher systematic error of 165.9 mL average overestimation found in our study.

Second, the physical factors of the patients, such as weight changes, postoperative edema, and scar tissue formation, are expected to influence the actual change in breast volume. Weight changes and scar tissue formation are not expected in patients undergoing breast augmentation with fat grafting due to the short follow-up period (less than 3 h). However, some postoperative edema is expected at the time of examination, which may account for some of the overestimation, but it is not reasonable to attribute the entire overestimation to edema.

The patients who received implants were examined 4–5 months after surgery, at which time no edema of significance is expected. Therefore, the measurement overestimation cannot be explained by edema in these patients. The patients who had breast implants experienced a mean weight gain of only 536 g, which is comparable to the weight of two breast implants; hence, we do not expect the changes in bodyweight to systematically influence the breast volume in this study. Overall, the limitations of this study cannot account for the large overestimations of changes in breast volume after breast augmentations found in this study.

Implications

Our findings raise concerns regarding the accuracy of using the most commonly used MRI breast volumetry technique for measuring fat graft volume retention in the breast.[7] Our results should be further investigated by other researchers to either confirm or refute the results. If confirmed, our findings could have potential implications for the interpretation of the results reported in many previous studies using the MRI technique to calculate fat graft volume retention.

Conclusion

This study represents the first attempt to validate the ability of the current MRI-based breast volumetry technique, described by Herold et al.[7] to measure changes in breast volume. The results of this validation study indicate that the current MRI technique is not suited for measuring changes in the breast volume and therefore should not be used to measure the volume retention of fat grafts in the breast. The average measured change in breast volume overestimated the true volume of breast augmentations by 50.8% in patients who had breast augmentation with implants and 50.9% in patients who had breast augmentation with fat grafting. Only 8 of the 168 individual measurements had measurement errors below 50 mL of the true change in breast volume. It is important to note that our study does not question the accuracy of the efficiency of the breast volumetry technique[5] to measure total breast volume, which was the original purpose of the technique.

We propose that a different approach for analyzing MRI scans to measure changes in the breast volume is needed with a higher accuracy to determine fat graft volume retention in breasts.

Conflicts of interest

None of the authors have financial interests related to the content of this manuscript. Activities not related to this article: Felix C. Müller is employed as an industrial Ph.D. student at Siemens Healthineers Danmark, cofounded by the Danish government fund “Innovationsfonden.”

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.bjps.2019.03.029.

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