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The Ratio of the Resected Specimen Volume to Breast Volume, as Measured by Three-Dimensional Surface Imaging, Is Associated With Aesthetic Outcome After Breast-Conserving Surgery

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ABSTRACT

Objective: An objective method to predict aesthetic outcomes after breast-conserving surgery (BCS) has not been established. The ratio of the resected specimen volume to breast volume (S/B ratio) may be a reasonable option for this purpose.

Materials and Methods: We recruited 32 breast cancer patients who underwent BCS. Preoperative breast volumes were measured using three-dimensional surface imaging (3DSI) and computed tomography (CT). The volume of the surgical specimens was estimated by the length, width, and height of the specimen. The S/B ratio was calculated from these values. The association between the S/B ratio and aesthetic outcome evaluated by an expert panel or by patient-reported outcomes was analyzed 1 year after BCS.

Results: There was a statistically significant association between the S/B ratio and aesthetic outcome evaluated by the expert panel when we used 3DSI to measure the preoperative breast volume ($p = 0.01$). An S/B ratio of <12.3% may represent a preliminary cut-off for predicting an excellent aesthetic outcome. This association was not observed when CT was used to measure breast volume ($p = 0.09$). Furthermore, there was no significant association between the S/B ratio and patient-reported outcome.

Conclusion: When 3DSI is used for breast volume measurement, the S/B ratio is associated with the aesthetic outcome after BCS. This advantage of 3DSI may be due to the upright position of the patients during the breast volume measurement.

Keywords: Breast neoplasms; breast-conserving surgery; aesthetic outcome; three-dimensional surface imaging

KEY POINTS

- The ratio of the resected specimen volume to breast volume (S/B) may help predict the aesthetic outcome after breast-conserving surgery.
- Breast volume measurement using three-dimensional surface imaging is useful for evaluating the aesthetic outcome.
- An S/B ratio of <12.3% may represent a preliminary cut-off for predicting an excellent aesthetic outcome.

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Introduction

Breast-conserving surgery (BCS) is a major procedure for the treatment of breast cancer. Approximately half of breast cancer patients undergo BCS in Japan (1). The aim of BCS is to prevent patients from suffering a sense of breast loss and to improve quality of life. Therefore, maintaining the shape of the breast is essential. If the breast is affected extensively by the disease and a good cosmetic outcome is not expected, mastectomy and breast reconstruction should be considered. For adequately judging whether BCS should be performed or not, reliable objective indicators are needed.

The ratio of the resected breast volume to whole breast volume may be a reasonable predictor of the aesthetic outcome after BCS. Many studies have investigated the impact of the ratio of the breast tumor volume to whole breast volume on aesthetic outcomes (2-5), and some of those studies have shown promising outcomes (6-8). Further studies are necessary in this area.

Recently, personal computers have improved in performance and become more affordable. These advances allow us to use a three-dimensional (3D) camera and process the resulting 3D images easily. Others attempted to use 3D cameras to evaluate the shape of the treated breast (9), but the results were unsatisfactory because the postoperative breast was evaluated at an unspecified time after the BCS (10).

In this study, we aimed to reveal the reliability of the ratio of the resected specimen volume to breast volume (S/B ratio) as an indicator of the aesthetic outcome after BCS. To achieve this, we prospectively recruited patients who underwent BCS and evaluated the association between the aesthetic outcome and the S/B ratio determined using 3D surface imaging (3DSI) or computed tomography (CT) to measure breast volume.

Materials and Methods

Ethical Statement

This study was approved by the Nihon University Itabashi Hospital Ethical Review Board (approval no: RK-220208-4, date: 10 February 2025) and was performed in accordance with the principles of the Declaration of Helsinki. We obtained written informed consent from all participants.

Study Participants

We recruited female breast cancer patients to investigate the usefulness of 3DSI for BCS. 3D imaging data were obtained before the operation. In addition, we obtained the demographic characteristics of the patients, clinical and pathological features of the breast cancer, and CT images.

3DSI Measurement of Breast Volume

We used the K3 3D camera system (Kiisya Corporation, Tokyo, Japan) to measure breast volume according to the manufacturer's manual (11). Briefly, 3D images were taken with the patient in the sitting position. The region of interest was outlined on the acquired image and retrieved using the equipped software. Using this software, the retrieved region was sectioned at a 1 cm interval, the size of the area from each section was obtained, and these values were summed to calculate the volume. Measurements were performed by two authors (HG and SF) independently, and the mean value was adopted. Approximately 10 minutes were required to obtain 3D images, including patient preparation and data saving, and an additional 10 minutes were needed to calculate breast volume. No additional costs were incurred for image acquisition.

CT Measurement of Breast Volume

CT scanning was performed preoperatively from the external acoustic meatus to the inferior margin of the ischial tuberosities for staging in each patient. The patients were placed in the supine position. In general, contrast medium was not used. Osirix® (Pixemo SARL, Swiss) software was used to calculate the breast volume measured by CT according to the manual. Briefly, the CT data were imported into this software, the margins of the sectioned breast image were traced in each slice, and the breast volume was calculated by summing the values of the traced area and multiplying by a section interval of 5 mm. The breast margins were defined as the breast skin surface and the outer lines of the muscle and bones of the thorax. Similar to the 3DSI measurement, the same two authors performed these measurements independently, and the mean value was adopted.

The Volume of the Resected Specimen

The surgically resected specimen was regarded as a column with an ellipse-shaped bottom. The long and short diameters of the bottom end and the height of the specimen were measured. The volume of the resected specimen was calculated using the following formula:

$$\text{Specimen volume} = (\text{long diameter})/2 \times (\text{short diameter})/2 \times \pi \times \text{height}$$

Panel Assessment of Aesthetic Outcome

One year after BCS, the cosmetic outcome of the surgery was evaluated by a panel of 12 members comprising experienced 8 nurses and 4 surgical oncologists who had over 10 years of clinical experience. One of these panelists assessed the aesthetic outcome in person for each participant. None of the members were involved in the surgical treatments, and all were blinded to the treatment histories of the patients. The aesthetic outcome was evaluated as shown in Table 1 (12).

Patient-Reported Outcomes

At the same time as the panel assessment of the aesthetic outcome, the patients completed the "satisfaction with breasts" module of the BREAST-Q, which is one of the most commonly used instruments for measuring patient-reported outcomes in breast cancer treatment (13). This module included 11 items. The summed scores for each item were converted to an equivalent transformed score according to the conversion table provided by BREAST-Q, and this score ranged from 0 to 100. Higher scores indicated better patient satisfaction with the surgical outcome. Furthermore, the patients completed the "adverse effects of radiation" module of the BREAST-Q, which consists of six items. In this module, each item was analyzed as a stand-alone measure, with the patient's response used directly as the item score. No composite or transformed scores were calculated.

Statistical Analysis

The relationship between 3DSI and CT breast volume measurements was investigated using Pearson's correlation coefficients. Linear regression analysis was used to generate regression lines. The association between the S/B ratio and panel assessment or patient-reported outcomes was analyzed using ordinal logistic regression analysis. Receiver operating characteristic (ROC) analysis was used to evaluate the ability of the S/B ratio to predict the aesthetic outcome. The statistical package R v4.0.3 (R Foundation for Statistical Computing, Vienna, Austria; ISBN 3-900051-07-0; http://www.R-project.org) was used for the statistical analyses. $p<0.05$ was considered significant.

Results

From May 2022 to July 2024, we recruited 39 breast cancer patients who underwent BCS. Of these, 7 patients were excluded from the analysis for various reasons (Figure 1). Although one patient lacked breast volume measurements by CT because of breast compression with an elastic bandage to achieve hemostasis, this patient was included in the study. Therefore, 32 patients were included in the analysis. However, CT-based breast volume measurements were available for only 31 patients.

The clinical and pathological characteristics of the patients are summarized in Table 2. The mean age of the patients was 59 years, the mean tumor size was 24.7 (range 10–75) mm, and the stage was 0 or I in 84.4% of the cases. Eleven cases (34.3%) had ductal carcinoma *in situ*-predominant lesions, defined as lesions in which the intraductal carcinoma component was larger than the invasive component. There were no cases with multifocal lesions. Five patients (15.6%) received adjuvant chemotherapy, and 24 patients (75.0%) received endocrine therapy. All patients underwent radiation therapy. Of these, four patients (12.5%) received boost radiation therapy, and two patients (6.3%) received supraclavicular radiation therapy.

The distributions of the 3DSI- and CT-measured breast volumes of the study patients are shown in Figure 2. The median (mean, range) breast volumes measured by 3DSI and CT were 428.9 (473.8, 160.0–1012.0) mL and 360.1 (396.9, 92.9–983.3) mL, respectively. The association between the 3DSI- and CT-measured breast volumes is summarized in Figure 3, and the Pearson's correlation coefficient was 0.68. The distribution of the surgically resected specimen volume is demonstrated in Figure 4; the median (range) volume was 45.5 (12.4–254.3) mL.

The relationship between the aesthetic outcome assessed by the expert panel and the S/B ratio measured by 3DSI or CT is shown in Figure 5. The low S/B ratio measured by 3DSI was significantly associated with a better aesthetic outcome [odds ratio per 1% increase in the S/B ratio, 1.14; 95% confidence interval (CI), 1.04–1.26; $p = 0.01$]. The proportional-odds assumption was evaluated using the nominal test and was not violated ($p = 0.653$). This tendency remained significant even after removal of the one patient who lacked CT-measured breast volume data

Table 1. Aesthetic outcome of the treated breast

Excellent	Treated breast was nearly identical to untreated breast.
Good	Treated breast was slightly different from untreated breast.
Fair	Treated breast was clearly different from untreated breast but not severely distorted.
Poor	Treated breast was severely distorted.

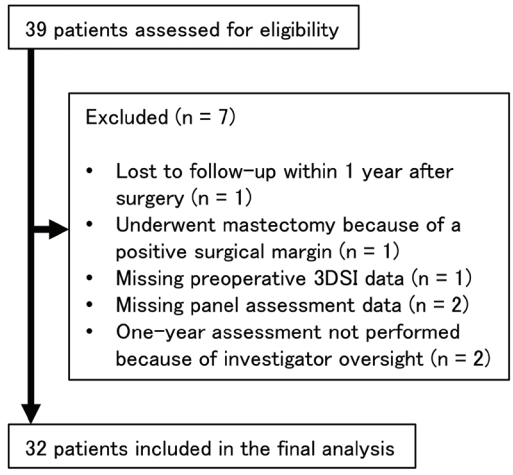

Figure 1. CONSORT-style flow diagram of patient selection, exclusions, and inclusion in the final analysis

3DSI: Three-dimensional surface imaging

due to elastic bandage compression. On the other hand, the low S/B ratio measured by CT showed the same trend, but the association with aesthetic outcome failed to reach statistical significance ($p = 0.09$).

Figure 6 shows the ROC curve assessing the ability of the S/B ratio measured by 3DSI to predict the aesthetic outcome determined by the panel assessment. Because ROC analysis requires a binary outcome, the four-category aesthetic assessment was dichotomized into an excellent outcome (8 cases) versus a good, fair or poor outcome (24 cases). The optimal cut-off S/B ratio distinguishing between the excellent aesthetic outcome and non-excellent outcome was determined by the Youden index to be 12.3%, with a sensitivity of 62.5%, a specificity of 100% and an area under the curve of 0.78 (95% CI, 0.62–0.94).

The patients were administered the "satisfaction with breast" module in BREAST-Q. However, we did not detect any significant association between the patients' answers and the S/B ratio measured by 3DSI (Figure 7). According to the "adverse effects of radiation" module of the BREAST-Q, 22 patients (68.7%) reported being a little bothered by at least one item, and 1 patient (3.1%) reported being a lot bothered by at least one item. Overall, 23 patients (71.8%) reported any bother from radiation.

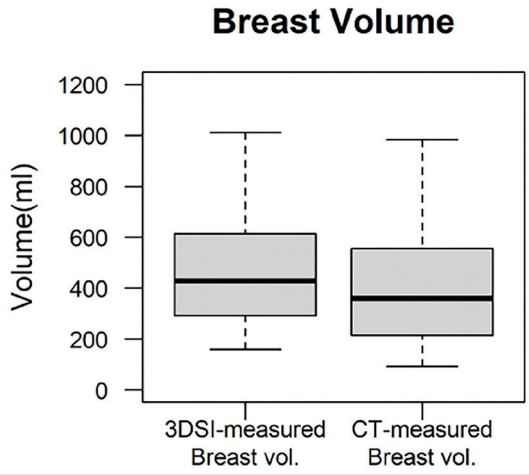

Figure 2. Distribution of the breast volumes measured by 3DSI versus CT. The median (range) volumes were 428.9 (160.0–1012.0) and 360.1 (92.9–983.3) mL when measured using 3DSI and CT, respectively. The horizontal lines within the boxes represent the median. The upper and lower sides of the boxes represent the 75th and 25th percentiles, respectively. The upper and lower whiskers extend to the largest value within 1.5×IQR above the 75th percentile and the smallest value within 1.5×IQR below the 25th percentile, respectively

3DSI: Three-dimensional surface imaging; CT: Computed tomography; IQR: Interquartile range

Table 2. Clinical characteristics of the study patients

No. of patients		32	
Mean age (range), years		59	(35–79)
Mean height (range), cm		160.0	(144.1–172.6)
Mean weight, kg		56.5	(37.2–82.9)
Mean body mass index (range)		22.0	(15.7–31.4)
Laterality	Right	14	43.8%
	Left	18	56.3%
Stage	0	4	12.5%
	I	23	71.9%
	II	5	15.6%
Mean tumor size (range), mm[§1]		24.7	(10–75)
Histology	Invasive ductal carcinoma	25	78.1%
	Mucinous carcinoma	3	9.4%
	DCIS	4	12.5%
DCIS-predominant lesion[§2]		11	34.3%
Chemotherapy		5	15.6%
Endocrine therapy		24	75%
Boost radiation therapy		4	12.5%
Supraclavicular radiation therapy		2	6.3%

[§1]: The size was measured microscopically. These tumors included both invasive and *in situ* lesions; [§2]: A DCIS-predominant lesion was defined as a lesion in which the intraductal carcinoma component was larger than the invasive component. There were no cases with multifocal lesions; DCIS: Ductal carcinoma *in situ*

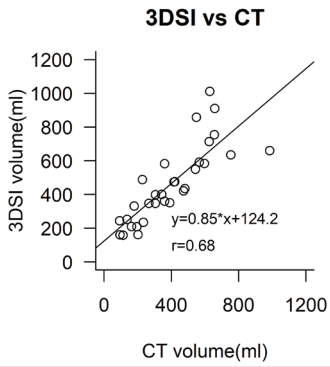

Figure 3. The relationship between the breast volume measured by 3DSI and that measured by CT. The correlation between the two breast volumes was moderate (R = 0.68)

3DSI: Three-dimensional surface imaging; CT: Computed tomography

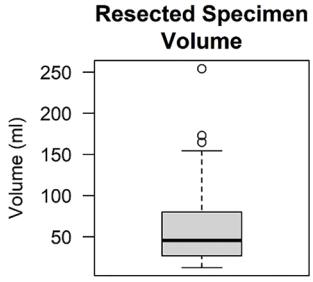

Figure 4. Distribution of the volumes of the resected specimen. The median (range) volume was 45.5 (12.4–254.3) mL. The boxplot parameters are the same as those in Figure 2

Discussion and Conclusion

We found that the S/B ratio is a reliable indicator of the cosmetic outcome after BCS based on the close association between the S/B ratio and aesthetic outcome as determined by a panel assessment. Furthermore, 3DSI-measured breast volume is more useful than CT-measured breast volume in this setting.

It is reasonable to expect the S/B ratio to be predictive of aesthetic outcomes after BCS. Several prior studies used the tumor volume rather than the resected specimen volume to evaluate aesthetic outcomes (2, 3, 6). Although tumor volume is easy to estimate preoperatively, there is a distinct difference between the tumor volume and resected specimen volume, and this discrepancy is likely to differ significantly among surgeons. Another issue is how to handle the case of multiple lesions or microcalcification. We believe that use of the S/B ratio should be evaluated extensively before using the tumor volume. On the other hand, the S/B ratio has an important limitation, as it cannot be accurately determined preoperatively. Future studies should investigate the association between the extent of disease and resected specimen volume.

Our study suggests that the ideal S/B ratio associated with an excellent aesthetic outcome after BCS is less than 12.3%. This estimate should be interpreted with caution because we have not yet performed a validation study. To our knowledge, two other studies reported similar thresholds, 10% and 14.6%, for evaluating the aesthetic outcome after BCS, as shown in Table 3 (6, 14). However, their approaches to measuring the breast and

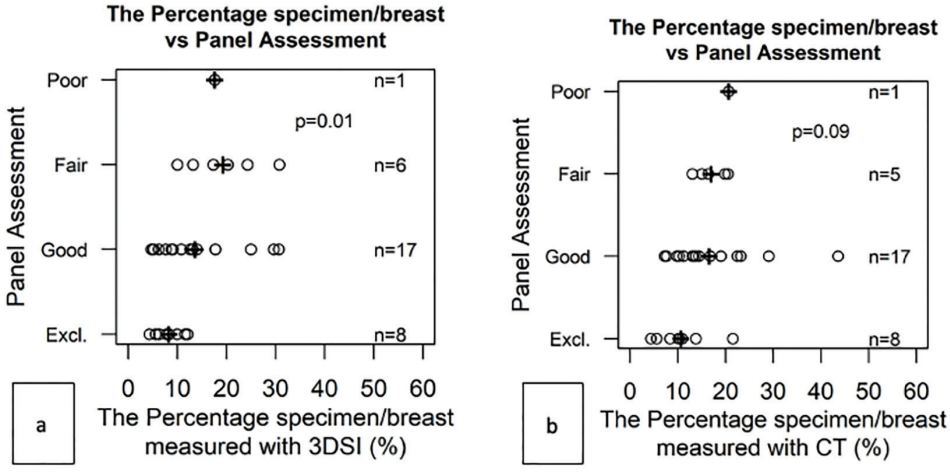

Figure 5. The association between the S/B ratio measured by 3DSI or CT and aesthetic outcome determined by the panel assessment. This association was statistically significant when breast volume was measured by 3DSI (a, $p = 0.01$) but not when measured by CT (b, $p = 0.09$). The plus signs indicate the mean of each category. "*n*" indicates the number of cases in each category

S/B: Specimen volume to breast volume; 3DSI: Three-dimensional surface imaging; CT: Computed tomography

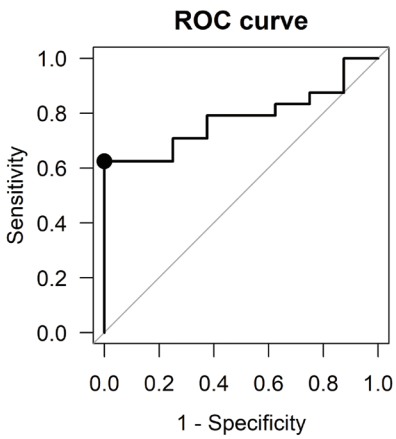

Figure 6. Receiver operating characteristic curve assessing the ability of the S/B ratio to predict an excellent cosmetic outcome based on the panel assessment. The black dot represents the Youden index

S/B: Specimen volume to breast volume; ROC: Receiver operating characteristic

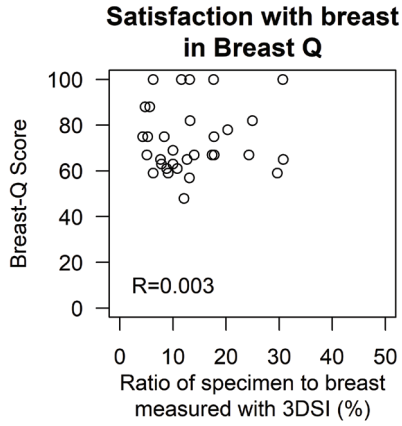

Figure 7. The association between the S/B ratio measured by 3DSI and the score for the "satisfaction with breast" module in BREAST-Q. The association was not significant ($r = 0.007$)

S/B: Specimen volume to breast volume; 3DSI: Three-dimensional surface imaging

specimen volumes and evaluating cosmetic outcomes differed from ours. More studies are necessary in this area.

Similar to several other studies (9, 15-18), we showed that the 3DSI-measured breast volume is useful for predicting aesthetic outcomes after breast surgery. Kim et al. (16) reported that 3DSI-measured breast volume is more useful than mastectomy specimen weight for predicting the ideal implant size for breast reconstruction. We used 3DSI, CT, magnetic resonance imaging, mammography, and resected mastectomy specimen to measure breast volume and found that the measured volumes were similar among the different modalities (11). However, breast volume measured by 3DSI is distinctly different from that measured by the other modalities because the patient is positioned exclusively upright during 3DSI measurement. Coltman et al. (19) reported differences in breast volume between the prone and standing positions ranging from approximately 8% to 22%. Because cosmetic assessment is performed for patients in the upright position, 3DSI-measured breast volume should be used to assess aesthetic outcomes after breast surgery. To our knowledge, our study is the first to show the usefulness of 3DSI for predicting aesthetic outcomes after BCS.

In contrast to the assessment of aesthetic outcomes by the nurse/surgeon panel, our study failed to show an association between the S/B ratio and patient-reported outcomes. Whereas Vos et al. (7) successfully demonstrated a positive association between a small tumor size and patient-reported aesthetic outcomes, other reports failed to reveal such an association (4, 5). Johansen et al. (20) reported a significant but relatively weak level of concordance between patients' and clinicians' evaluations of the cosmetic results. We believe that patients' evaluations of aesthetic outcomes are complicated by many factors including adjuvant chemotherapy, endocrine therapy, and radiation therapy. In particular, radiation therapy is a well-known confounder or effect modifier of aesthetic outcomes, and 71.8% of our patients were affected. This treatment possibly plays a more significant role in patient satisfaction than panel-based assessments. Importantly, the S/B ratio alone cannot determine aesthetic outcomes after BCS, and should not be regarded as a standalone tool for clinical decision-making.

Table 3. Comparison of S/B ratio among relevant studies

Study group	Sample size	Measurement of specimen volume	Measurement of breast volume	S/B ratio
Cochrane et al. (6)	151	Estimated from tumor size	Mammography	10%
Hashem et al. (14)	36	Actual specimen size	Mammography	14.6%
Present study	32	Actual specimen size	3DSI	12.3%

3DSI: Three-dimensional surface imaging; S/B: Specimen volume to breast volume

Our study has some limitations. The number of patients was small. The patient-reported outcomes did not support the outcomes of the panel assessment. Because each participant was evaluated by a single panelist, inter-rater reliability could not be assessed. Future studies should include independent assessments by multiple panelists for each participant to evaluate the reproducibility of the aesthetic assessment. Aesthetic outcomes after BCS are influenced by several factors, including tumor location, absolute breast size, body mass index, and boost radiation. Because of the limited sample size, we were unable to adjust for these potential confounding factors in the present analysis. We did not evaluate aesthetic outcomes beyond 1 year after surgery. The breast size of our cohort was relatively small, with a median volume of 428.9 mL. Although this study was performed prospectively, some data were missing. The volume of the resected specimen was estimated based on the resected specimen's length, width, and height, instead of actual volume measurements. Because multiple statistical associations were examined without adjustment for multiple comparisons, our findings should be interpreted with caution, and confirmation in a larger independent cohort is warranted. However, we believe that our conclusions were not impaired significantly even after consideration of all these limitations.

In conclusion, the S/B ratio is a useful indicator of cosmetic outcomes after BCS. Furthermore, 3DSI-measured breast volume is more useful than CT-measured breast volume for this evaluation. More studies are needed to achieve the same conclusions with patient-reported outcomes and to investigate the utility of the relationship between the extent of disease and the resected sample volume for predicting cosmetic outcomes preoperatively in BCS patients.

Ethics

Ethics Committee Approval: This study was approved by the Nihon University Itabashi Hospital Ethical Review Board (approval no: RK-220208-4, date: 10 February 2025) and was performed in accordance with the principles of the Declaration of Helsinki.

Informed Consent: We obtained written informed consent from all participants.

Footnotes

Authorship Contributions

Surgical and Medical Practices: S.F., H.G., Y.H., K.T.; Concept: Y.H., K.T.; Design: K.T.; Data Collection and/or Processing: S.F., H.G.; Analysis and/or Interpretation: S.F., K.T.; Literature Search: Y.H., K.T.; Writing: K.T.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

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