White Paper

Insight BD

Automated and integrated breast density assessment for objective classification

siemens-healthineers.com/mammography

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Contents

1. Introduction

Full-field digital mammography (FFDM) is currently the gold standard when it comes to breast cancer screening [1]. It delivers high-resolution images of the breast, however, it can have some drawbacks. One is that its diagnostic accuracy can depend on a woman's breast density – the relative amount of fibroglandular tissue inside the breast.

The topic of breast density has received increased attention and has grown in importance over recent years and now plays an indispensable role in state-of-the-art breast imaging. It has even led to the formation of a large International Consortium on Mammographic Density (ICMD), where researchers from 22 countries are analyzing epidemiological and mammographic density data from general population studies to characterize determinants of mammographic density more precisely, and to evaluate whether they are consistent across populations worldwide [2].

1.1 Clinical relevance

From a clinical point of view, the breast density is relevant for two reasons. First, a high breast density may weaken the diagnostic accuracy of FFDM. The fibroglandular tissue might mask lesions, leading to lower sensitivity in women with dense breasts [3–8]. This is demonstrated in Figure 1, with an increasing number of missed cancers for higher breast densities.

Second, breast density is proven to be an independent risk factor for breast cancer, with a higher risk for women with denser breasts [9–11]. The increased number of detected and missed cancers in women with dense breasts is a clear effect of this (see Figure 1).
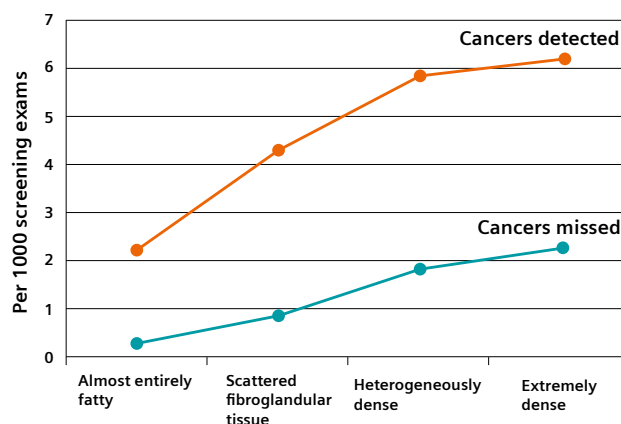

Figure 1: The breast cancer detection rate (orange line) increases for higher breast density categories, being a clear effect of the increased cancer risk in women with dense breasts. The number of cancers missed (blue line) also increases with breast density, being the result of lower sensitivity of FFDM in women with dense breasts. Data from Carney et al. [3], Table 3.

1.2 Breast density changes clinical practice

As a result of its clinical relevance, breast density has taken on a more central role in breast exams. For example, in certain US states, legislation requires the breast density to be an integral part of the radiological report and women to be informed if they have dense breasts [12–14]. In a recent proposal, the FDA advises that the lay summary provided to women after a mammography exam should identify whether the woman has low or high density breasts [15]. This would apply to all women, and not only to those with dense breasts, and to all US states. As a consequence, public awareness for this topic has increasingly become more prominent, including initiatives like the Are You Dense Advocacy [16] and educational resources like DenseBreast-info.org.

Another example comes from Austria, where the role of breast density for additional screening modalities is being investigated. The Tyrolean breast cancer screening program explores the addition of ultrasound examinations for all women with dense breasts participating in the screening program [17]. In this setup, the breast density determines whether or not to apply additional screening modalities.

1.3 Why Insight BD?

To facilitate an efficient and automated integration of breast density assessment into the standard clinical workflow, Siemens Healthineers has introduced Insight Breast Density (Insight BD) with the market introduction of its latest mammography system MAMMOMAT Revelation.

It delivers automated breast density assessment for objective classification of the volumetric breast density (VBD). As such, it delivers quantitative, reproducible, consistent and more precise breast density assessment, while overcoming inter-reader variability. The Insight BD measurements are directly available on the acquisition workstation (AWS) after an FFDM view or a 50° wide-angle digital breast tomosynthesis (DBT) view has been acquired, supporting instant decision making on additional screening procedures in women with dense breasts.

This white paper on Insight BD aims to:

- explain how Insight BD works and how it was validated;
- demonstrate the algorithm robustness;
- show comparisons with human readers; and
- highlight its advantages that enable efficient and instant results in clinical routine.

Parts of the scientific results in this white paper have been achieved in collaboration with the Skåne University Hospital in Malmö (Sweden).

2. The biology of breast density

The female breast is composed of variable proportions of different tissues (Figure 2), among them [18]:

- fatty and fibrous tissue that give breasts their size and shape;
- milk-producing glands, the so-called lobules or glandular tissue; and
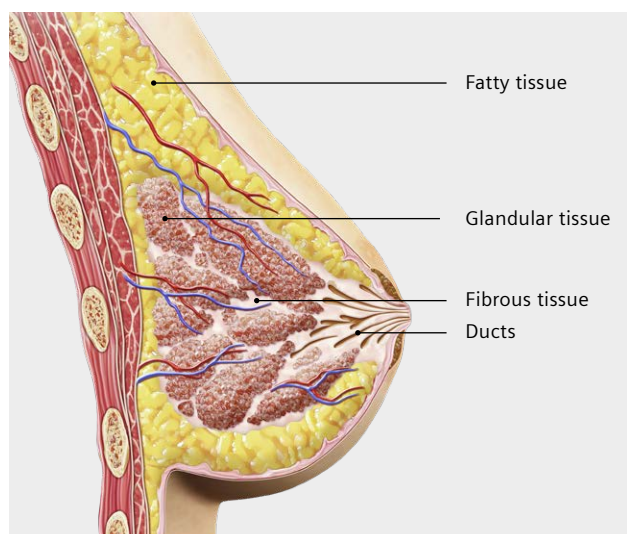- ducts that carry the milk from the lobules to the nipple.

Figure 2: Breast density is the relative amount of fibroglandular tissue inside the breast.

Two of these tissues define the breast density: the glandular and the fibrous tissue. The combination of both tissues is also known as fibroglandular tissue. Now, the breast density is defined as the relative volume of fibroglandular tissue in proportion to the total breast volume. A low breast density means a low proportion of fibroglandular tissue and a high breast density a high proportion of fibroglandular tissue.

The breast density can change during a woman's life, as summarized in a comprehensive review paper [19]:

- Genes are the dominant factor accountable for the breast density (60-65%), leaving 35-40% for lifestyle and reproductive factors.
- In the general population, the breast density decreases with age and shows lower values for postmenopausal than for premenopausal women.
- Among women with a high body mass index (BMI) and women with a large breast size, the breast density is typically lower because of the higher proportion of fatty tissue.
- Breast density is affected by drugs. For example, tamoxifen can lead to a decrease in breast density, whereas hormone replacement therapy may increase the breast density.

Factors like urbanization and degree of social deprivation can also result in differences in breast density [20], and ethnicity is also significantly associated with breast density [21, 22].

3. Methods to assess breast density

In a regular mammogram, the fibroglandular tissue appears as brighter structures, because it has a higher mass attenuation coefficient than fat [23, 24]. To assess the relative amount of breast density, both subjective and quantitative (objective) methods exist.

3.1 Subjective assessment
Subjective methods have been used for many decades, in which radiologists perform a visual appraisal of the patterns and distribution of fibroglandular structures inside the mammogram. Examples are the Wolfe patterns [25], the Tabar classification [26] and the well-known Breast Imaging Reporting and Data System (BI-RADS) of the American College of Radiology (ACR) [27]. In its current 5th edition, the BI-RADS density classification results in purely subjective categories between a and d (see Figure 3), without estimating the percentage values of fibroglandular tissue (as had been the case in the 4th edition [28, 29]).

In the United States, the proportion of women with dense breasts (c or d) is estimated to be around 50%, with a distribution for the breast density categories a to d of roughly 10%, 40%, 40% and 10% respectively [30].

Subjective methods are quick and need nothing but the radiologist's eye, but also have several drawbacks, as has been extensively described in the scientific literature. Subjective assessments have no gold standard by definition and therefore, studies cannot evaluate the accuracy of subjective BI-RADS density determinations.

Even more important are the undesirable effects inherent in the subjective assessment: inter-reader variability and reproducibility issues. Many studies have demonstrated that visual assessment of breast density is observer-dependent [31, 32] and that the reproducibility of the BI-RADS breast density categorization is compromised. As an example, different radiologists assign the same BI-RADS density category to the same case only in about 80% of cases [33, 34], and the same radiologist categorizes 23% of women into a different BI-RADS density category on subsequent screening exams [35]. Further, more than 70% of radiologists are not always confident about their BI-RADS breast density categorizations [36].
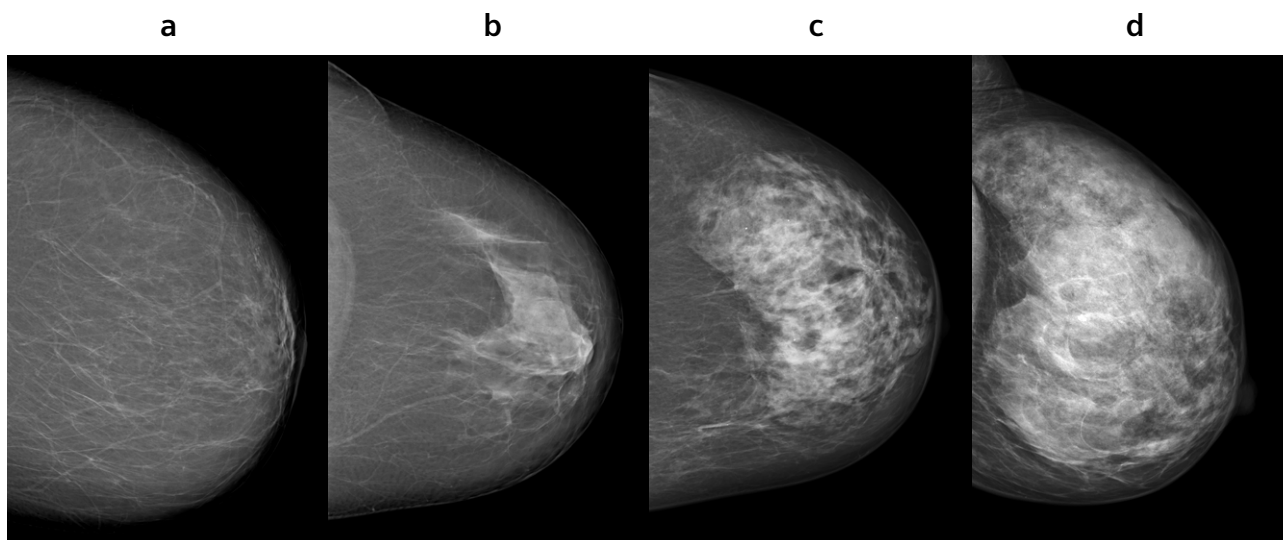
| a | b | c | d |

Figure 3: The Breast Imaging Reporting and Data System (BI-RADS) has four subjective categories of parenchymal breast density on mammograms: a – almost entirely fatty, b – scattered areas of fibroglandular density, c – heterogeneously dense, which may obscure small masses and d – extremely dense, which lowers the sensitivity of mammography. (Images courtesy of Prof. Dr. D. Uhlenbrock, Dortmund, Germany)

3.2 Developments towards quantitative assessment

In the breast imaging community, the wish for quantitative breast density assessment is clearly present. Recent statements include: "automated computerized techniques are needed to fully overcome the impact of subjectivity" [37] and that "quantitative approaches (...) allow more precise and reliable measurement than possible with subjective and qualitative techniques" [24].

Initial methods towards breast density quantification were area-based methods, in which the area of fibroglandular tissue in a mammogram was quantified as a fraction of the entire breast area. Examples are the visual analogue scale (VAS) in which radiologists had to estimate the percentage of mammographic density between 0-100% [38] and semi-automated, interactive thresholding techniques, like the Cumulus method [39] as illustrated in Figure 4.
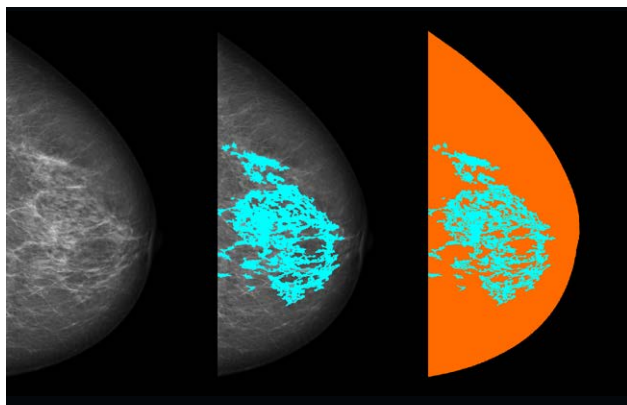
These area-based methods still suffered from subjectivity, either through the estimation of the area or in manually setting the threshold for the gray value above which pixels are considered to be fibroglandular tissue. Also, it was not possible to take tissue overlap into account and as such the quantification of 2D information of a 3D phenomenon remains suboptimal [40]. This is illustrated in Figure 5, in which a different volumetric breast density can still result in the same area percentage.

Furthermore, area-based methods have been shown to be dependent on the view (CC or MLO) and the amount of compression [41]. For these reasons, area-based methods have been surpassed by volume-based methods.
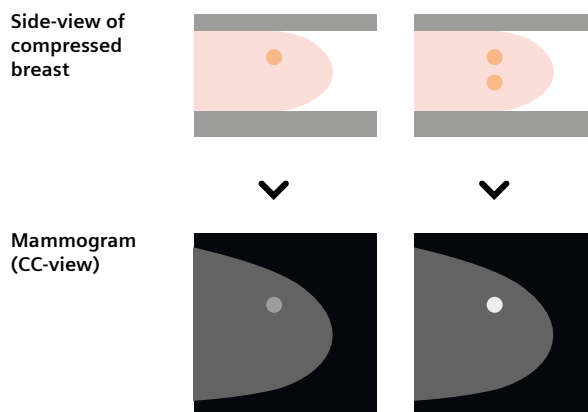
Figure 4: By manually setting a threshold for a particular gray level, the selected area of the fibroglandular tissue in the mammogram can be quantified. In this example, the area of fibroglandular tissue (blue) is 16.8% of the entire breast area (orange+blue). Still, this method is not truly objective as the result depends on the (subjective) threshold level.

Figure 5: Illustration to demonstrate the major drawback of area-based methods. From the two side views of the compressed breasts, it is clearly noticeable that the right breast has a higher volume of dense tissue (dark orange) than the left breast. Although the signal intensity in the right mammogram is higher, the area of dense tissue in both CC views is the same. With area-based methods this would result in the same area percentage and thus, the same breast density – this is clearly wrong. (The idea of this illustration is based on Figure 3 from the publication of Ng et al. [41].)

5 cm compressed breast thickness

1 Pixel

Physics

0.2 cm fibroglandular tissue

4.8 cm fat tissue

Volumetric breast density for this pixel: **4%**

1 Pixel

Physics

1.5 cm fibroglandular tissue

3.5 cm fat tissue

Volumetric breast density for this pixel: **30%**
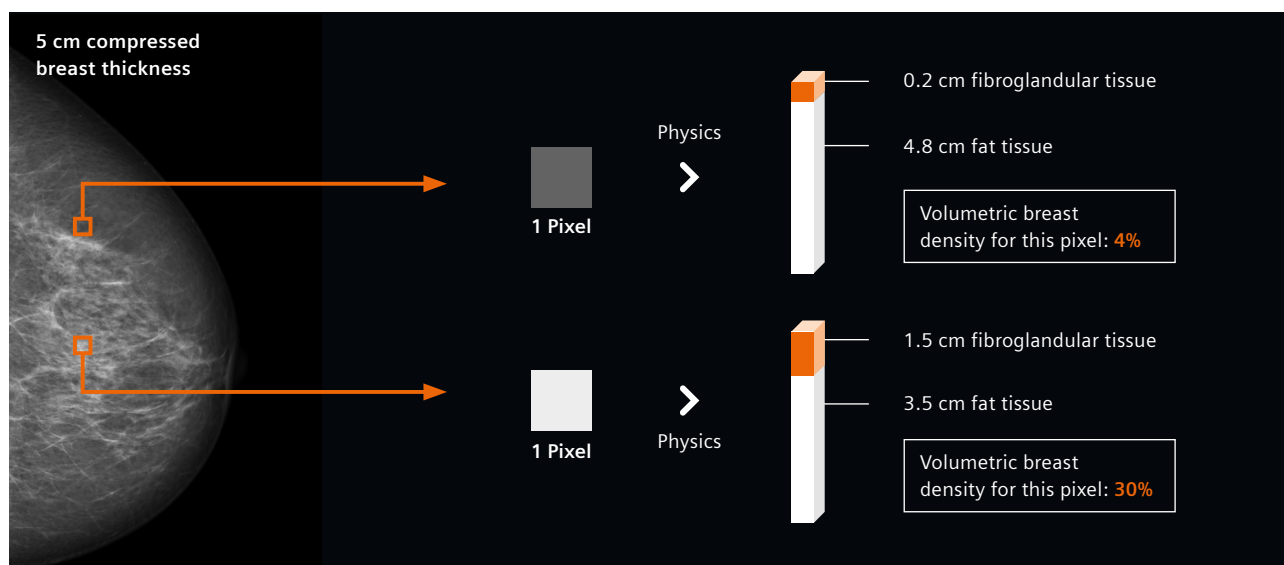
3.3 State-of-the-art quantitative breast density assessment: volume-based methods

Volume-based methods quantify the volume fraction of fibroglandular tissue (not its area) inside the entire breast volume. By applying physics (see next chapter), this information can be derived from the pixel intensities in the 2D mammograms together with the acquisition parameters (Figure 6). Computer algorithms can do these calculations very fast and allow for automated analysis of the volume-based breast density.

From the known compressed breast thickness and the number of pixels indicating breast tissue, the total breast volume in cm³ as well as the partial volume of the fibroglandular tissue (cm³) can be calculated. With this information, the volume fraction of dense tissue with respect to the entire breast volume can be expressed as:

Figure 6: Principle of determining the volumetric breast density. Based on the compressed breast thickness and acquisition parameters, for each pixel inside the breast its intensity is resolved into fat and fibroglandular tissue with the aid of known physics principles. The volumetric breast density for a particular image is computed by averaging over all pixels.

$$\text{Volumetric breast density (\%)} = \frac{\text{volume of fibroglandular tissue (cm}^3)}{\text{volume of entire breast (cm}^3)} \times 100$$

4. Insight BD: automated volumetric breast density assessment

The software application Insight BD delivers the volumetric breast density for FFDM and DBT images acquired with the MAMMOMAT Revelation. For FFDM acquisitions, the algorithm works on the raw images ("for processing") and for DBT acquisitions on the low-dose central projection of the 2D tomosynthesis raw data. Insight2D images (synthetic mammograms) are not processed by Insight BD; rather they receive the same volumetric breast density as their underlying DBT stacks.

4.1 Physical model

The Insight BD algorithm applies a physical model of the image acquisition process and it assumes that the breast consists of fibroglandular and fatty tissue only (Figure 7). First, a reference region is selected in the image, where the pixel values represent fatty tissue only. As for both tissue types the energy-dependent X-ray attenuation values are known (μ_{gland} and μ_{fat}) and the compressed breast thickness is also known, the amount of fibroglandular tissue can be calculated for each pixel. To then calculate the volumetric breast density, the total amount of fibroglandular tissue in the image is divided by the total breast volume, which is determined using the known compressed thickness of the breast, its projected surface area in the image and a 3D shape model. Because of this image-based approach, calibration scans are not required. More details on the algorithm can be found in the original publication by Fieselmann et al. [42].

Repeated processing of one single image will always result in the identical volumetric breast density, as Insight BD is a deterministic algorithm (a particular input, will always produce the same output).
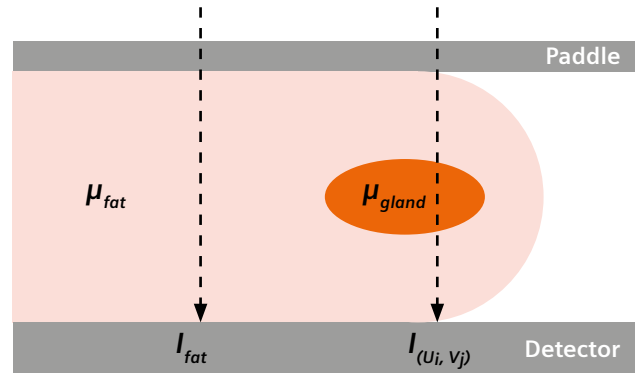

Figure 7: Illustration of a compressed breast with a certain thickness. The Insight BD algorithm automatically selects a reference region where the breast consists of fatty tissue only (I_{fat}). Based on the measured X-ray attenuation in a certain pixel ($I(u_i,v_j)$), the known values for fibroglandular and fatty tissue (μ_{gland} and μ_{fat}), the attenuation in the reference region and the compressed breast thickness, the amount of fibroglandular tissue can be determined for each pixel.

4.2 Masking risk score

In addition to computing the volumetric breast density, a masking risk score is also calculated from the volumetric density map. This score addresses how the glandular tissue is distributed inside the breast and indicates the probability that small masses may be obscured due to locally accumulated glandular tissue. For example, if the total volume of fibroglandular tissue is distributed homogeneously in the whole breast, the masking risk is low. On the opposite, if all fibroglandular volume is accumulated in one place, the masking risk is high.

This masking risk score is an inaccessible parameter inside the algorithm and plays a role in the assignment of the breast density categories b and c (see next paragraph).

4.3 Density grade index (DGI)

As radiologists have been working with visual breast density assessment for decades, providing them with only a numerical breast density percentage would not be helpful. For this reason, a correspondence between the volumetric breast density and the ACR's well-known BI-RADS breast density classification is necessary. The density grade index (DGI) converts the quantitative, volumetric breast density into four categories, correlating to the BI-RADS classification:

a) The breast is almost entirely fatty.

b) There are scattered fibroglandular densities.

c) The breast tissue is heterogeneously dense, which could obscure detection of small masses.

d) The breast tissue is extremely dense. This may lower the sensitivity of mammography.

The conversion of the volumetric breast density [%] into a density grade index [a-d] depends on the threshold values between the categories (Figure 8). The masking score only plays a role for volumetric breast densities around the threshold between b and c. If the masking risk is high, index c will be assigned, so that it can be considered a dense breast (categories c and d), and supplemental screening examinations like ultrasound can be initiated.

The default thresholds between the four density categories have been determined in a reader study where North American radiologists provided their BI-RADS density classifications for FFDM images. In combination with the retrospectively calculated VBD values from these images, the thresholds were then calibrated to obtain the highest possible correspondence. If needed, the thresholds may be adjusted to fit to the preferences of the end user.
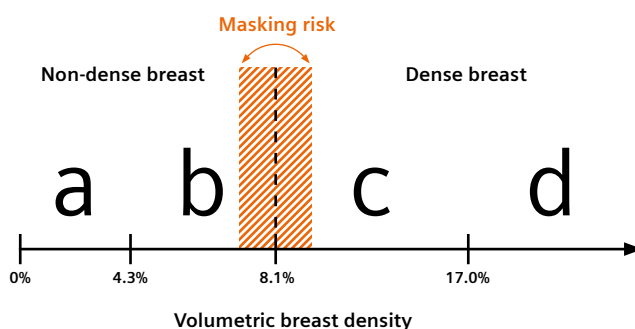

Figure 8: The volumetric breast density is converted into a density grade index (DGI). Around the threshold between categories b and c, the masking risk score is taken into account (dashed area).

4.4 Display of results

At the AWS, the results of Insight BD are displayed in each single image as well as in a pop-up window (Figure 9). The results contain four values:

- Volume of fibroglandular tissue (cm³)
- Total breast volume (cm³)
- Volumetric breast density (%)
- Density grade a-d

To obtain a single breast density result for each individual woman, the different views of the left and right breast should be combined. How this is performed with Insight BD is shown in Figure 10. Depending on the configuration, either the average volumetric breast density or the highest breast density of the left and right breast can be chosen as the breast density for the woman overall.

Figure 9: Example of the Insight BD dialog box on the AWS.

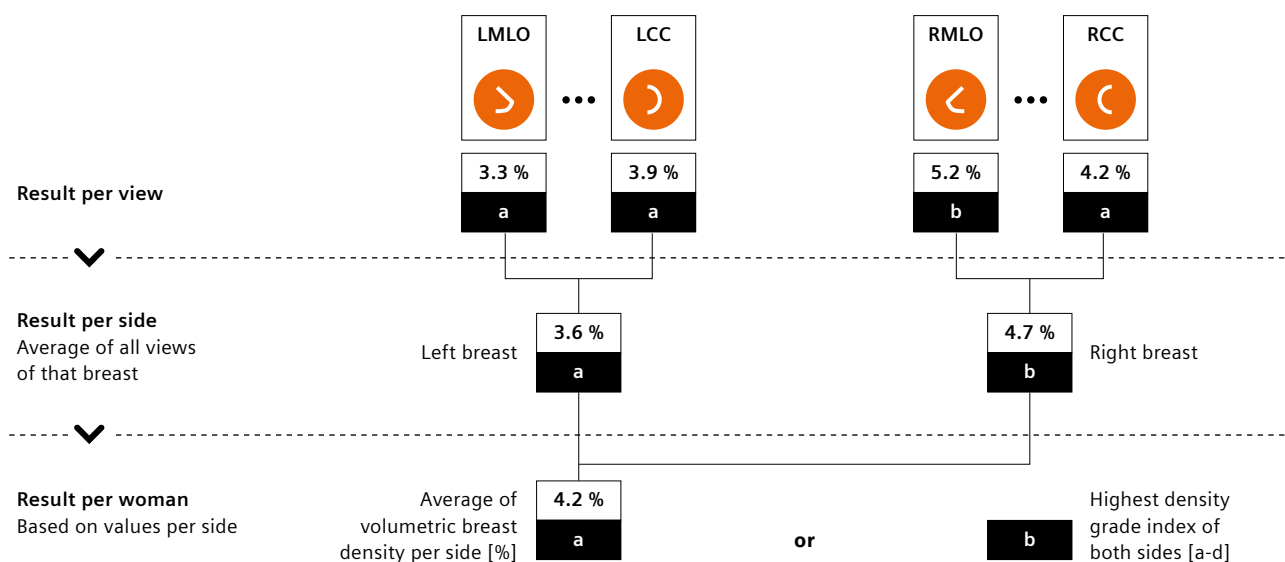**Figure 10:** Schematic diagram with a numerical example of how the different breast density scores are combined to obtain a single density grade index for each woman. Depending on the configuration, either the average breast density or the highest breast density of the left and right breast can be chosen as the breast density for the woman overall. Threshold values in this example are based on Figure 8.

5. Insight BD: validation

An algorithm aiming for objective quantification of the volume fraction of fibroglandular tissue should deliver accurate, reproducible, and consistent results. These goals for volume-based breast density assessment have also been described in scientific literature [41], among which:

1. Density should be the same for the identical image of the breast.
2. Density should be similar for different views of the same breast (e.g. CC and MLO).
3. Density of the left and right breast should be highly correlated (but not necessarily identical).

4. Density should be similar for the same breast, irrespective of the imaging equipment (e.g. FFDM or DBT).
5. Density over a population should generally reduce with age.

Recently, Fieselmann et al. investigated all these points in a scientific publication (open access), demonstrating that Insight BD delivers accurate, repeatable, reproducible, and consistent measurements of volumetric breast density [43], as summarized in Figures 11-17.

Accuracy

A measurement can be said to be accurate if its average value is close to the true value of the quantity being measured.

The accuracy of Insight BD has been assessed using breast tissue equivalent phantom experiments resulting in a mean absolute error of 1.7–3.4 percentage points, being equivalent to an average accuracy of 3.8% for the volumetric breast density.

Figure 11

VBD measured in ROIs [%]
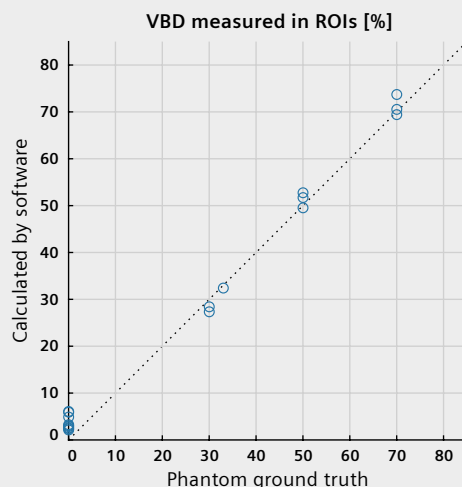
Repeatability

Reprocessing of a particular image of the breast should result in identical volumetric breast density.

As Insight BD is a deterministic algorithm, repeated processing of one single image will always result in identical volumetric breast density.

Figure 12

Reproducibility

When a certain quantity is measured under slightly different conditions, the reproducibility is a measure of how high the agreement between the obtained measurement results is. In this particular case, the reproducibility of Insight BD is relevant, e.g. for the agreement between the volumetric breast density derived from different views or different acquisition modes of the same breast.

Left / right breast

The volumetric breast density of the left and right breast should be highly correlated, but not necessarily identical, as clinical studies with other volumetric techniques have shown [44–46].

Based on 8,150 clinical exams, Insight BD has a Pearson correlation coefficient of 0.937 (p<0.001) and a mean absolute deviation of 1.5 percentage points between the left and right breast.

Figure 13

VBD [%]

Y-axis: R (average of RCC and RMLO)
X-axis: L (average of LCC and LMLO)

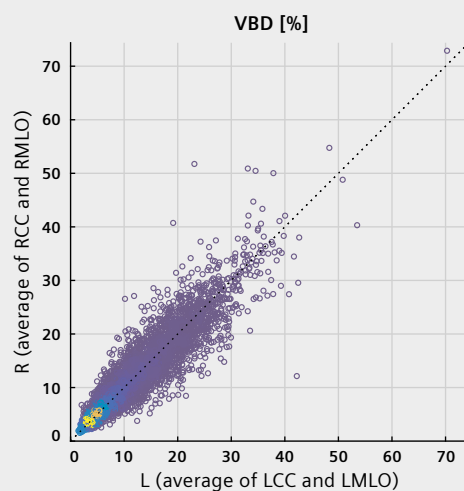### CC / MLO view

The volumetric breast density should be similar for different views.

Based on 8,150 clinical exams, Insight BD has a Pearson correlation coefficient of 0.926 (p<0.001) and a mean absolute deviation of 2.2 percentage points between CC and MLO views.

Figure 14

VBD [%]

Y-axis: MLO (average of LMLO and RMLO)
X-axis: CC (average of LCC and RCC)
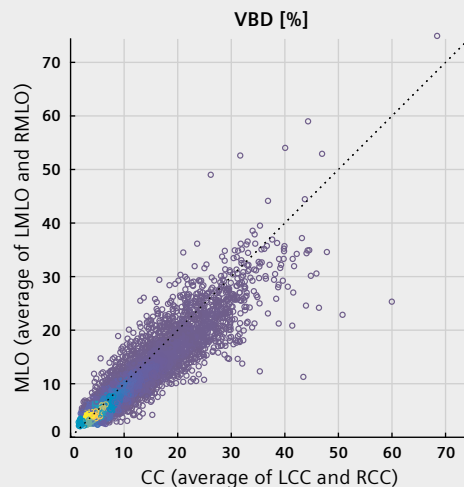
FFDM / DBT
The volumetric breast density should be similar, irrespective of the imaging equipment (e.g. FFDM or DBT).

Based on 108 clinical exams, Insight BD has a Pearson correlation coefficient of 0.900 (p<0.001) and a mean absolute deviation of 2.8 percentage points between FFDM and DBT acquisitions.

VBD [%]

PRIME / standard FFDM
The volumetric breast density should be similar for the same breast, irrespective of the acquisition technique (e.g. standard grid-based FFDM or grid-less FFDM acquisition with software-based scatter correction (PRIME)).

Based on 74 clinical exams, Insight BD has a Pearson correlation coefficient of 0.995 (p<0.001) and a mean absolute deviation of 0.7 percentage points between standard grid-based FFDM and FFDM with PRIME.
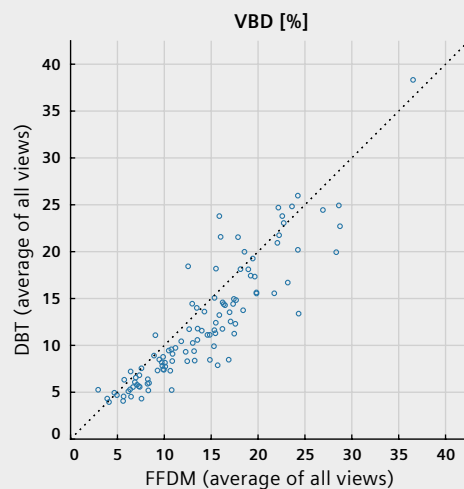

VBD [%]
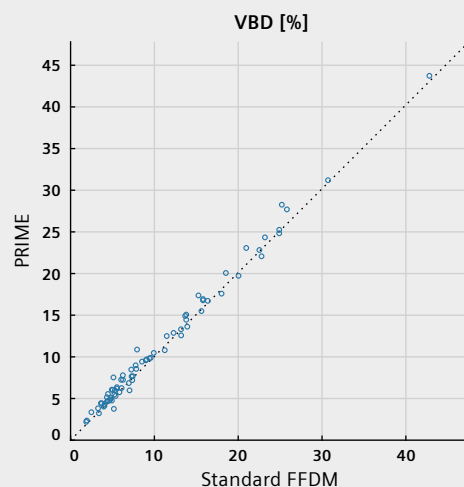
Consistency

For a new algorithm it is important to demonstrate consistency, i.e. showing agreement with typical behavior described in existing scientific literature. For Insight BD, it is expected that due to the postmeno-pausal alteration of fibroglandular breast tissue, the volumetric density of a woman's breast will decrease with increasing age [47, 48].

After sorting all 8,150 volumetric breast densities according to patient age, it is observed that the proportion of women with a high breast density (c or d) decreases with age, as expected.

Figure 17

VBD [%]

Legend:
□ Density category a or b
◇ Density category c or d

Frequency [%] vs Age [years]
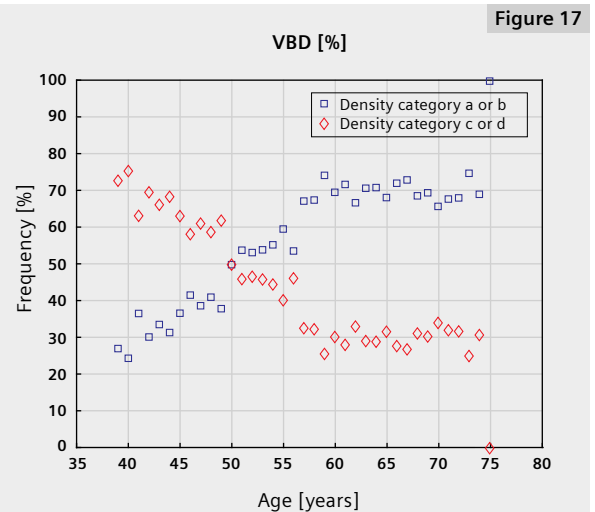
5.1 Performance comparison

There are already third party (multi-vendor) products for automated volumetric breast density assessment on the market. In Table 3 of the scientific publication (open access) of Fieselmann et al. [43], the values of the accuracy, reproducibility and consistency of a reference software product can be found. Note that third party products for automated volumetric breast density don't have the advantage of being instantly available at the AWS at the time of acquisition.

6. Insight BD: comparison with human readers

As explained in section 4.3, in addition to the volumetric breast density [%], Insight BD delivers a corresponding density grade index [a-d]. To validate this density grade index, Fieselmann et al. performed a clinical study to evaluate the agreement between Insight BD's density grade index and radiologists' visual assessments according to the ACR BI-RADS classification [43].

6.1 Study setup

Six hundred anonymized 4-view FFDM exams were randomly selected from the Malmö Breast Tomosynthesis Screening Trial [49], and 32 experienced radiologists from the US and Canada assessed visual breast density classifications for these exams according to the ACR BI-RADS (5th edition). The most frequently chosen density category for a certain exam, a so-called panel majority vote (PMV), was used for the comparison with Insight BD.

All 600 exams were subsequently analyzed by Insight BD, resulting in a density grade index between a–d for each exam. In addition, the DBT exams (MLO-view) from 512 of the 600 exams were also analyzed by Insight BD.

From this data, the overall percentage agreement (percentage of cases in which Insight BD and the PMV resulted in the same density category) was calculated, as well as Cohen's linearly weighted kappa (κ_{lw}), which measures the inter-rater agreement for categorical items and takes the possibility of agreement occurring by chance into account.

6.2 Results

The agreement between the radiologists' panel majority vote (PMV) and the density grade index results from Insight BD are shown in the following tables. Tables 1 and 2 show the results for all four breast density categories, whereas Tables 3 and 4 show the results for a dichotomous categorization in non-dense (a/b) and dense (c/d) breasts.

Table 1:		Radiologists' PMV according to BI-RADS			
FFDM (n=600)		**a**	**b**	**c**	**d**
Insight BD	a	71	61	0	0
	b	25	174	31	1
	c	1	36	136	7
	d	0	0	21	36
Agreement 69.5%; κ_{lw} = 0.67					

Table 2:		Radiologists' PMV according to BI-RADS			
DBT (n=512)		**a**	**b**	**c**	**d**
Insight BD	a	49	33	2	0
	b	33	155	38	2
	c	1	44	101	7
	d	0	0	21	26
Agreement 64.6%; κ_{lw} = 0.59					

Table 3:		Radiologists' PMV according to BI-RADS	
FFDM (n=600)		**Non-dense** (a/b)	**Dense** (c/d)
Insight BD	**Non-dense** (a/b)	331	32
	Dense (c/d)	37	200
Agreement 88.5%; $\kappa_{lw} = 0.76$			

Table 4:		Radiologists' PMV according to BI-RADS	
DBT (n=512)		**Non-dense** (a/b)	**Dense** (c/d)
Insight BD	**Non-dense** (a/b)	270	42
	Dense (c/d)	45	155
Agreement 83.0%; $\kappa_{lw} = 0.64$			

6.3 Interpretation

Insight BD delivers results that correlate well with the visual assessment done by radiologists. This is indicated by the majority of cases lying on the diagonals of the tables (gray background), and is directly reflected in the high agreement percentages. Especially for the dichotomous case, when discriminating dense from non-dense breasts, the agreement is markedly high. An agreement of 100% might seem desirable from a clinical point of view, but cannot be expected from a scientific point of view, as will be elucidated in the following.

For new technologies and algorithms, it is important to have a benchmark to compare with. For automated volumetric breast density assessment algorithms, this benchmark is the use of the ACR BI-RADS breast density classification, which for decades has been and still is considered the standard. Although a direct comparison between the results of both methods can be made, it is important to be aware of the fundamental differences between the methods themselves.

As described in Section 3.1, the visual ACR BI-RADS classification is a subjective assessment of breast density by a radiologist and suffers from inter-reader variability and reproducibility issues. In contrast, Insight BD is a deterministic thus reproducible, physics-based algorithm, objectively quantifying the amount of volumetric breast density [%]. As these methods differ fundamentally, neither of them can be considered as having the "true" value. Both deliver valid results, each of them in their own way*.

From a scientific, methodological point of view, Insight BD is clearly better than the subjective visual assessments of the ACR BI-RADS categorization. However, at the same time, it neglects the extensive experience radiologists have with visual breast density classification. A potential mismatch between a result of Insight BD and visual assessment should thus be interpreted as an "unexpected" rather than a "wrong" outcome of the algorithm*. Obviously, it is important to gain more experience with the results of Insight BD and build up trust in its results. In view of the extensive experience radiologists might have with visual assessment, the use of Insight BD requires potentially relearning and should be supported as well as possible.

In scientific literature, very similar results can be found in studies comparing the volumetric breast density software of another vendor with the visual assessments of radiologists. For the four-scale categorization (a-d), the reported agreement varies between 57.1 and 70.1% and for the dichotomous categorization in non-dense and dense, agreement values range between 81.8 and 91.5% [46, 50, 51].

To conclude, Insight BD delivers results that correlate well with the visual assessment done by radiologists.

* Insight BD only to be used as adjunctive information when the final breast density assessment is made by a medical professional.

7. Insight BD: clinical implementation

The performance and consistency of Insight BD, as described in the previous chapters, delivers excellent preconditions for clinical implementation. In addition, Insight BD may support instant risk stratification right at the AWS, improving process efficiency and accelerating supplemental screening decisions. Its versatility and added value for the clinical workflow will be illustrated with the following example.

7.1 Clinical workflow improvement – An example from Switzerland

Consider the screening environment in the Kantonspital Basel Land-Liestal (Switzerland), in which 2-view FFDM is acquired for each breast (Figure 18). If the radiologist categorizes the breasts as being dense (c or d), an additional DBT acquisition is performed in the MLO view for both breasts.

This workflow without Insight BD has some drawbacks:

• Each woman has to wait until the breast density assessment has been performed, and might even need to come back for a second visit.

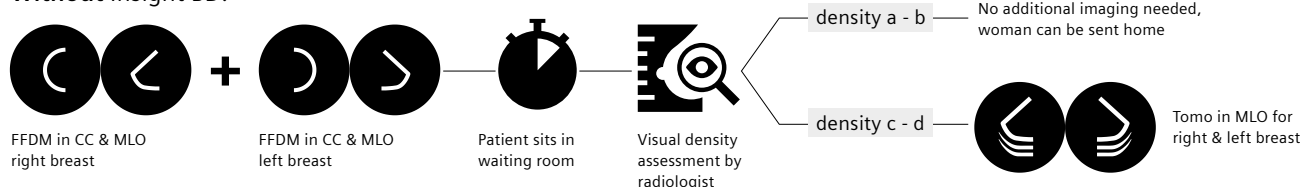• In women with dense breasts, the MLO-view is acquired twice (first as FFDM, then as DBT).

With the implementation of Insight BD at the Kantonspital Basel Land-Liestal (Switzerland), these issues have been resolved, resulting in clear advantages:

• The breast density information is directly available at the AWS after the FFDM acquisitions, with 0 seconds delay to classification. The decision to acquire the DBT MLO views in women with dense breasts can be made while the woman is still at the acquisition system*.

• The FFDM MLO views can be skipped in women with dense breasts, thus saving radiation dose and examination time in these women.

This optimized workflow with Insight BD has proven to be successful in clinical routine. The chief radiographer at this hospital, Ms. Regula Hurni, explains**: "We have integrated the Insight BD automated breast density measurement as a standard in our diagnostic examination procedure. First, we take a 2D mammography image of each breast in CC. Together with the X-ray image, I can see the breast density values directly on the screen, I know immediately whether I should acquire the MLO image using tomosynthesis or whether conventional 2D mammography is sufficient. For example, if the breast is dense, category c or d, I will perform a tomosynthesis exam."

Without Insight BD:

FFDM in CC & MLO right breast + FFDM in CC & MLO left breast → Patient sits in waiting room → Visual density assessment by radiologist → density a - b → No additional imaging needed, woman can be sent home

density c - d → Tomo in MLO for right & left breast

With Insight BD:

FFDM in CC for right & left breast → InBD Automated breast density assessment → density a - b → FFDM in MLO for right & left breast

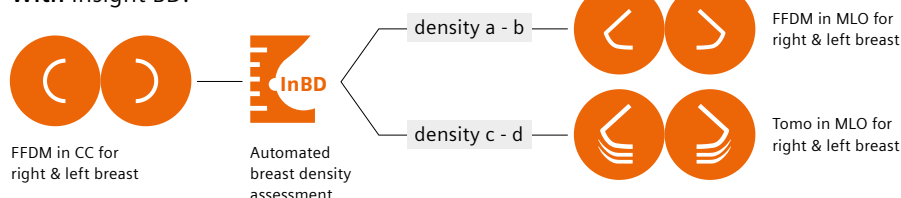density c - d → Tomo in MLO for right & left breast

Figure 18: Example from the Kantonspital Basel Land-Liestal (Switzerland). With the implementation of Insight BD in the clinical workflow, the efficiency can be increased, examination times reduced and radiation dose lowered.

* *Insight BD only to be used as adjunctive information when the final breast density assessment is made by a medical professional.*

** *Customer statement 20.9.2018 – The statements by Siemens Healthineers' customers described herein are based on results that were achieved in the customer's unique setting. Since there is no "typical" hospital and many variables exist (e.g., hospital size, case mix, level of IT adoption) there can be no guarantee that other customers will achieve the same results.*

8. Discussion and conclusions

The use of automated volumetric breast density assessment based on FFDM and DBT acquisitions is straightforward, as FFDM is the current standard in breast cancer screening and DBT its potential successor. Nevertheless, there are also other possibilities for automatically assessing breast density, and the future might hold new applications in addition to the workflow advantages described in the previous chapter.

8.1 Alternative technologies under research
In additional to the calculation of the physical volumetric breast density, a couple of other methods have been described for assessing measures of breast density. They can be roughly divided into two categories. The first category is the application of other image analysis methods based on FFDM and tomosynthesis images, and the second category consists of alternative imaging techniques.

An example of the first category is the prediction of the masking risk through statistical and texture metrics [52]. By taking these metrics into account, in this study the masking risk for cancers could be more accurately predicted than by density alone, suggesting that texture metrics may be useful in models to guide a stratified screening strategy. Also, an increasing number of deep-learning algorithms is being developed for automated breast density classification [53–55]. Nevertheless, these algorithms do not provide the physics-based volumetric breast density, but rather risk scores and observer-like categorizations.

Volumetric breast density cannot only be determined from FFDM and DBT images, but also from alternative imaging techniques. One example currently under research is the dual energy methodology, aiming to quantify the amount of fatty and fibroglandular breast tissue [56, 57]. This is different from e.g. TiCEM, as no contrast agent has to be used. For the sole purpose of breast density quantification, this dual energy approach will probably not prevail, as it has generally a higher radiation dose than FFDM and/or DBT. Another investigational method for quantifying breast density uses MRI [58–60], but this is outside the scope of this white paper.

8.2 Future applications
New applications of breast density quantification tend towards risk stratification and personalized screening, as breast density has been shown to be a risk factor significantly associated with diagnoses of interval cancers versus screen-detected cancers [8]. Initial studies have been performed, indicating an important role for automated breast density assessment in personalized screening strategies [41, 61, 62].

8.3 Conclusion
Insight BD is a robust algorithm delivering objective, accurate, repeatable, reproducible and consistent breast density classification and correlating well with the visual assessment done by radiologists. As Insight BD is directly available at the acquisition workstation, it can improve the process efficiency in several ways and is tailored to each clinical work-stream. As such, it is the preferred breast density assessment tool for MAMMOMAT Revelation, enabling efficient and instant volumetric breast density assessment in clinical routine.

Abbreviations

2D	Two-dimensional
3D	Three-dimensional
ACR	American College of Radiology
AWS	Acquisition workstation
BI-RADS	Breast Imaging Reporting and Data System
BMI	Body mass index
CC	Cranio-caudal
DBT	Digital breast tomosynthesis
DGI	Density grade index
FFDM	Full-field digital mammography
ICMD	International Consortium on Mammographic Density
Insight BD	Insight Breast Density
LCC	Left CC view
LMLO	Left MLO view
MBTST	Malmö Breast Tomosynthesis Screening Trial
MLO	Medio-lateral oblique
PMV	Panel majority vote
PRIME	Progressive Reconstruction Intelligently Minimizing Exposure
RCC	Right CC view
RMLO	Right MLO view
ROI	Region of interest
TiCEM	Titanium contrast-enhanced mammography
VAS	Visual analogue scale
VBD	Volumetric breast density

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