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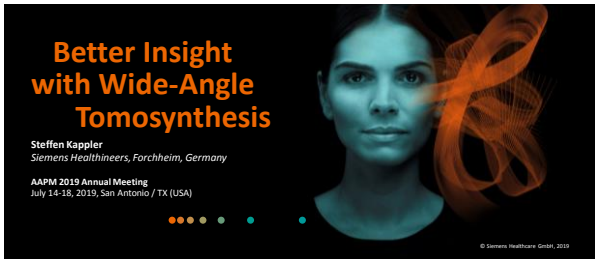

Disclosure & Disclaimer

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Dr. Steffen Kappler is full-time employee of SIEMENS Healthcare GmbH, Forchheim, Germany. In addition, Steffen is private stake-holder of SIEMENS AG and Siemens Healthineers AG.

Presented products or solutions are not commercially available in all countries. Due to regulatory reasons their future availability cannot be guaranteed. Parts of the presented systems, methods, or algorithms are part of research projects; they are not commercially available and future availability cannot be guaranteed.

Outline

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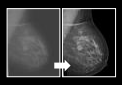
Introduction
Wide-angle Digital Breast Tomosynthesis
System Design & Image Reconstruction
Synthetic Mammograms (2D & 3D)
Grid-less Applications
TiCEM Dual-Energy Technique
Tomosynthesis-guided Biopsy
Short Outlook to the Future
Conclusion

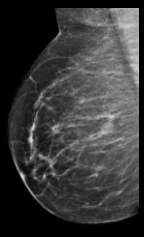
SIEMENS MAMMOMAT Revelation
http://siemens.com/mammomat-revelation

Introduction
Image Quality in Breast Cancer Screening

Basic Image Quality Requirements
- Highest spatial resolution (details, µCalc)
- Excellent contrast reproduction (tumors, …)
- Standardized (but region-specific) image appearance
- Efficient suppression of scatter radiation effects
- Lowest possible radiation dose

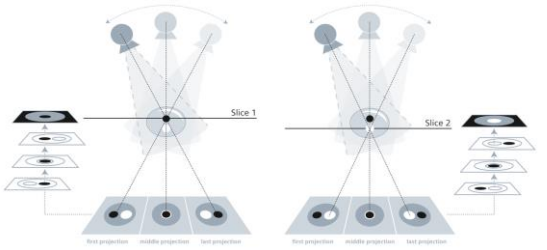
Challenges in X-ray Breast Imaging
- High resolution measurement system
- Complex image processing of large high-resolution image matrices
- Scatter compensation





Reading challenge: Huge amount of anatomical background!

Introduction
Anatomical Background Reduction: Digital Breast Tomosynthesis



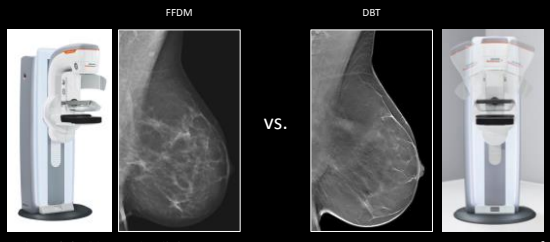
Introduction
Anatomical Background Reduction: Digital Breast Tomosynthesis

FFDM

vs.

DBT

Introduction
Anatomical Background Reduction: Digital Breast Tomosynthesis

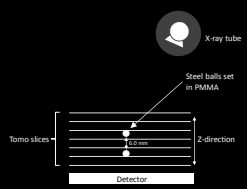


Images by courtesy of Prof. T. Helbich, Vienna General Hospital (AKH).

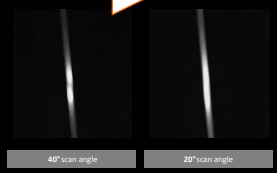
7

Wide-Angle Digital Breast Tomosynthesis: 40° vs. 20° Experiment
Stronger reduction of tissue overlap with wider acquisition angles

Experiment: Phantom with two 1.0 mm steel balls 6 mm apart in z-direction



Learning: Wider scan angles significantly increase depth resolution!



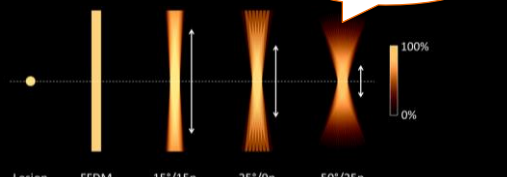
Reference: Mertelmeier T, Ludwig J, Zhao B, Zhao W. In Krupinski E (ed.) Lecture Notes in Computer Science 5116 Digital Mammography: 9th International Workshop, IWDM 2008, pp 220-227, Springer-Verlag Berlin Heidelberg (2008).

8

Wide-Angle Digital Breast Tomosynthesis
Stronger reduction of tissue overlap with wider acquisition angles

Illustration: Probability Maps of Lesion Location

Learning: Wider scan angles significantly increase depth resolution!



9

Wide-Angle Digital Breast Tomosynthesis
Improved low-contrast lesions detection

Learning: Better depth resolution improves detection of tumor masses and low-contrast lesions!

Comparison Study: Narrow- and Wide-angle DBT

Part 1: Simulation study using a cascaded linear system model (CLSM)

Results: reduced in-plane breast structural noise and increased in-plane detectability of masses with wide-angle DBT

Part 2: Clinical pilot study comparing mass conspicuity

Results: masses are more conspicuous in wide-angle DBT

→ Detection of mass lesions in dense breasts can be improved by increasing the angular range in DBT

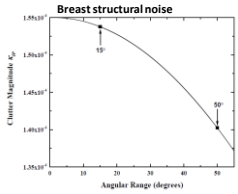

Impact of angular range of digital breast tomosynthesis on mass detection in dense breasts

Reference: Sciuto DA, Huang H, Liu C, Rinaldi K, Hebecker A, Mertelmeier T, Vogt S, Fisher P, Zhao W, "Impact of angular range of digital breast tomosynthesis on mass detection in dense breasts," Proc. SPIE 10718, 14th IWBI, 2018; 107181V; doi: 10.1117/12.2318243.

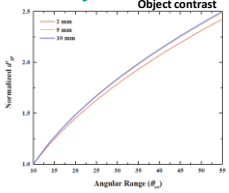
Wide-Angle Digital Breast Tomosynthesis
Improved low-contrast lesions detection

Learning: Better depth resolution improves detection of tumor masses and low-contrast lesions!

Breast structural noise

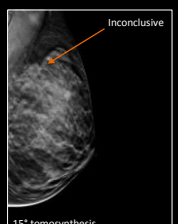


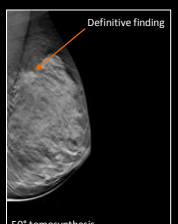
Object contrast

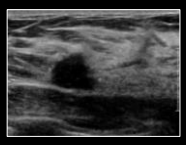


Reference: Sciuto DA, Huang H, Liu C, Rinaldi K, Hebecker A, Mertelmeier T, Vogt S, Fisher P, Zhao W, "Impact of angular range of digital breast tomosynthesis on mass detection in dense breasts," Proc. SPIE 10718, 14th IWBI, 2018; 107181V; doi: 10.1117/12.2318243.

Clinical Case: Definitive Finding with Wide-Angle Tomo
Ultrasound-confirmed, invasive ductal carcinoma grade 2







Note: Ultrasound clearly demonstrates a lesion with malignant appearance

Images: Courtesy of Dr. Peter Champness

Guiding Principle

“Deliver better insight with wide-angle tomosynthesis”

Wide-Angle System Design: MAMMOMAT Revelation
Overview

50° wide-angle tomosynthesis*
High depth resolution for better tissue separation.[1)]

Insight 2D and 3D*
Faster reading of tomosynthesis volumes with the synthetic visualization in 2D and 3D.[2)]

HD Breast Biopsy*
Target accuracy of +/- 1mm based on 50° wide-angle tomosynthesis.

InSpect – Integrated Specimen Tool*
Specimen scan within 20 seconds directly on the mammography system.

TiCEM – Titanium Contrast Enhanced Mammography*
Additional diagnostic information to confidently detect or rule out lesions.

Insight BD – Breast Density assessment*
Objective classification for instant risk stratification directly at the acquisition workstation.

Personalized Soft Compression
Increased patient comfort and consistent image quality.

PRIME Technology
Dose reduction by up to 30%[3)] without compromising image quality.

* Option
1) Maldera et al. (2016): Digital breast tomosynthesis: Dose and image quality assessment. Physica Medica, pp. 1-12.
2) Uchiyama N. et al. (2016): Diagnostic Usefulness of Synthetic MMG (SMMG) with DBT (Digital Breast tomosynthesis) for Clinical – Setting in Breast Cancer Screening. Springer International Publishing Switzerland. IWDM 2016, LNCS 9699, pp. 59–67.
3) Compared to grid-based acquisition with Mammomat Inspiration, depending on breast thickness - L.B. Larsen, A. Fieselmann, H. Pfaff, T. Mertelmeier: Performance of grid-less digital mammography acquisition technique for breast screening: analysis of 22,117 examinations Presentation B-1025 ECR 2015.

Wide-Angle System Design: MAMMOMAT Revelation
Technical Specifications

X-ray tube	Tungsten anode, 1 mm inherent beryllium filtration
X-ray beam filter	Anode/filter combinations: W/Rh, W/Ti
Anti-scatter grid	Grid ratio 5:1, 31 lines/cm
Detector technology	Amorphous Selenium (aSe, 85µm pixels)
Detector size	24 cm x 30 cm (9.5″ x 12″)
System swivel range	+180° to -180°, motorized, isocentric rotation
Tomo mode swivel range	-25° to +25° (with 25 projections)
Source-image distance	65 cm (25.6″)
Height adjustment	69 cm (27.2″) to 150 cm (59.1″) (object table)

Wide-Angle System Design: MAMMOMAT Revelation
High-Performance X-ray Measurement System

X-ray generator & tube	Tungsten anode, 1 mm inherent beryllium filtration
Power (IEC 60601-2-45)	5 kW (30 kV, 1 s)
kV range	23…35 kV / 45…49 kV for Dual-Energy
mAs range at 25 kV	2…630 mAs in mAs mode, 7…715 mAs in AEC mode
Exposure times	10 ms to 4 s (large focus) / 60 ms to 6 s (small focus)
Focal spot size (IEC 60336)	0.3 mm (large) / 0.15 mm (small)
X-ray beam filter	Anode/filter combinations: W/Rh, W/Ti
Anti-scatter grid	Grid ratio 5:1, 31 lines/cm
Flat detector	Amorphous selenium (aSe)
Pixel size	85 µm x 85 µm squared
Detector size	24 cm x 30 cm (9.5" x 12")
Image matrix	2816 x 3584

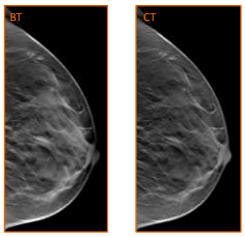
Wide-Angle Tomosynthesis Image Reconstruction: EMPIRE
Algorithm Outline

Enhanced Multiple Parameter Iterative Reconstruction

EMPIRE Main Processing Steps
- Super-resolution reconstruction (0.2 mm) using FBP with statistical artifact reduction
- Slab calculation (2.0 mm, 50% overlap) for better visualization of calc clusters and smoother scrolling
- Iterative noise reduction

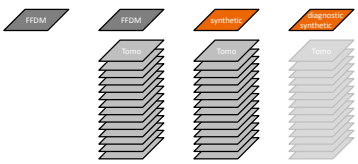
EMPIRE Image Flavors
- BT – soft breast tissue contrast enhancing
- CT – standard reconstruction

Study on Image Quality
100 patients, 4 readers (standard FBP vs. EMPIRE), better overall image quality, contrast, and visibility of calcifications



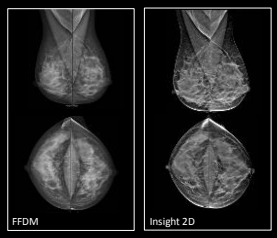
Reference: Rodriguez-Ruiz A, Teuwen J, Vreemann S, Bouwman RW, van Engen RE, Karssemeijer N et al. (2017) New reconstruction algorithm for digital breast tomosynthesis: better image quality for humans and computers. Acta Radiologica, 59(9), 1051–1059. https://doi.org/10.1177/0284185117748487

Synthetic Mammograms
Motivation



Synthetic Mammograms (insight2D)
Concept

- **Navigational tool** with digital breast tomosynthesis
- Ideal for an **easy comparison with prior FFDM** and tomosynthesis exams
- **40% dose reduction as opposed to FFDM as** an adjunct to tomosynthesis[1)]

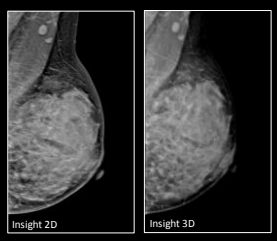


1) Uchiyama N. et al. (2016) Diagnostic Usefulness of Synthetic MMG (SMMG) with DBT (Digital Breast tomosynthesis) for Clinical – Setting in Breast Cancer Screening. Springer International Publishing Switzerland. IWDM 2016, LNCS 9699, pp. 59–67.

19

Rotating Synthetic Mammograms (insight3D)
Concept

- **Unique, rotating 3D display** in breast tomosynthesis
- **Faster reading** of tomosynthesis exams[1)]
- **Easier analysis of micro calcifications** at a glance[1)]
- **Comprehensive visualization** of findings for surgeons, referring physicians, and patients



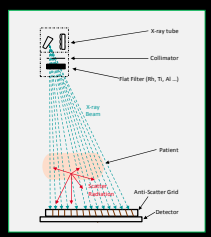
1) Tani H, Uchiyama N, Machida M, Kikuchi M, Arai Y, Otsuka K et al. (2014) Assessing Radiologist Performance and Microcalcifications Visualization Using Combined 3D Rotating Mammogram (RM) and Digital Breast Tomosynthesis (DBT). In: Fujita H, Hara T, Muramatsu C (eds) Breast Imaging. Springer International Publishing. Cham, pp 142–149.

20

Scatter Radiation Effects in X-ray Imaging

Brief Introduction to Scatter Radiation

- Scattering processes destroy the intended absorption imaging geometry (i.e. straight lines from focal spot to detector)
- We distinguish 2 types of scattered radiation, from:
  - tube or its vicinity → image blur
  - Patient or its vicinity → degrade image SNR
- Typically, scatter from the patient is dominant and does not contribute to the useful imaging process. However,
  - it produces a low-frequency background intensity
  - it reduces contrast
  - it increases quantum noise



21

Grid-less Applications for FFDM (PRIME)
Concept

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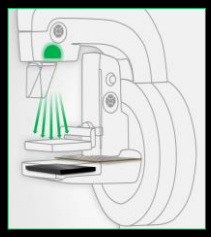
Post-breast anti-scatter grids partially block primary radiation

Amount of scatter radiation scales with breast size

For small & mid-size breast grid removal enables full use of primary radiation:
- significant dose reduction potential
- scatter modifies image quality and impression

Solution: Combination of automated breast-size dependent* grid removal, OpDose, adaptive AEC Algorithm, and a scatter correction algorithm, where:
- software identifies scatter-causing structures
- algorithm restores image quality and impression

***Note:** grid is removed for compression thicknesses below 70 mm.



22

Grid-less Applications for FFDM (PRIME)
Results

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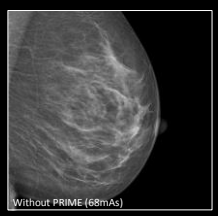

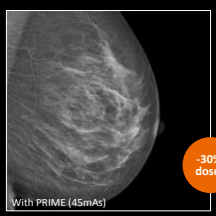

1) Compared to grid-based acquisition with Mammomat Inspiration, depending on breast thickness - L.B. Larsen, A. Feselmann, H. Pfaff, T. Mertelmeier. Performance of grid-less digital mammography acquisition technique for breast screening: analysis of 22,117 examinations Presentation B-1025 ECR 2015

Images: Courtesy of MVZ Prof. Dr. Uhlenbrock & Partners, Dortmund, Germany

23

Grid-less Applications for FFDM (PRIME)
More Results

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Grid-less mammography: excellent performance proven in screening routine

- Significant reduction of average dose (up to 30% less dose)
- Uncompromised image quality
- No negative impact on
  - cancer detection rate
  - recall rate

	Number of women	Recall rate	Cancer detection rate	Specificity
Without PRIME (12 months)	>50,000	2.59%	0.55%	97.96%
With PRIME (5 months)	>20,000	2.44%	0.55%	98.11%

Reference: Comparison of screening performance metrics and patient dose of two mammographic image acquisition modes in the Danish National Breast Cancer Screening Programme - A. Abdi, A. Feselmann, H. Pfaff, T. Mertelmeier, L.B. Larsen, ECR 2018, 320: 180-191

24

Contrast-enhanced Dual Energy Mammography

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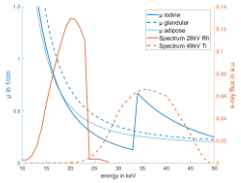
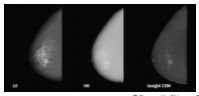
Dual Energy Iodine Imaging

- Mass attenuation coefficients of breast tissue and iodine contrast exhibit different characteristics
- Classical dual-energy technique for computation of an iodine-only material image applies
- Titanium filter applied to high-energy X-ray beam maximizes spectral separation
- Motion compensation and excellent scatter compensation are essential pre-requisites
- Iodine image by weighted subtraction of low (LE) and high (HE) energy images





Contrast-enhanced Dual Energy Mammography (TiCEM)

Titanium filter maximizes spectral separation

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Dedicated high energy 1.0 mm titanium X-ray filter with high X-ray yield:

- Excellent spectral separation between low and high energy X-ray beam
- Up to 60% higher tube output compared to 0.3 mm Cu

→ Enables consecutive examinations without tube overheating

Reference: Hörnig MD et al. Design of a contrast-enhanced dual-energy tomosynthesis system for breast cancer imaging. In: Proc. SPIE 8313: Medical Imaging 2012: Physics of Medical Imaging, 2012; 83134O.

Contrast-enhanced Dual Energy Mammography (TiCEM)

Titanium filter maximizes spectral separation

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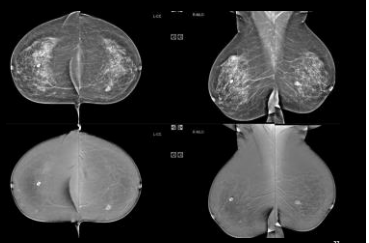
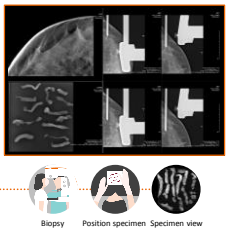
- BI-RADS 5, density category b
- CEM: Tumor with contrast enhancement

- Contrast: Iodine-based
- Volume 1.5 ml/kg + NaCl bolus
- Concentration: 370 mg/ml / Flow: 3.0 ml/s
- Time after injection: 2:00 min



Tomosynthesis-guided Biopsy (HD Breast Biopsy & InSpect)

50° tomo provide better depth resolution than 30° stereo



Simplified workflow illustration. Workflows may vary in different countries and clinics.
Clinical images: Courtesy of MVZ Prof. Dr. Uhlenbrock & Partners, Dortmund, Germany

28

Short Outlook to the Future

Innovations in Mammography

State-of-the-Art High-End Systems provide:

- Fast workflow
- CC & MLO view for left & right breast
- Digital Mammography & Tomosynthesis
- Magnification mode
- Stereotactic biopsy
- Contrast-enhanced mammography

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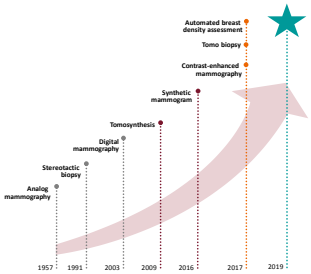


29

Conclusion

Wide-angle digital breast tomosynthesis significantly increases depth resolution and improves detection of tumor masses and low-contrast lesions

To "deliver better insight" was guiding principle for the wide-angle system design of the **MAMMOMAT Revelation**

The **EMPIRE Image Reconstruction** was introduced to improve overall image quality, contrast, and visibility of calcifications

The **insight2D synthetic mammograms** are great navigational tools and allow comparison with prior FFDM exams

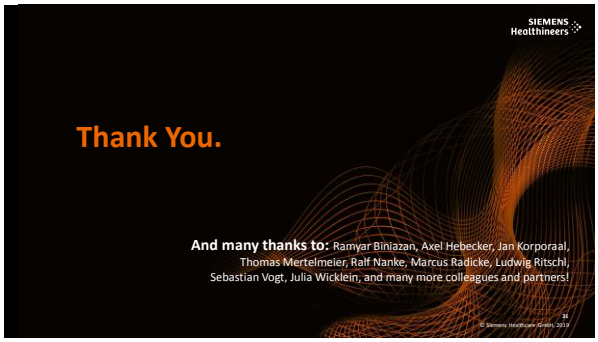
The **insight3D rotating synthetic mammograms** enable easier analysis of micro calcifications and provide comprehensive visualization of findings

The **PRIME grid-less technique** enables significant dose reduction for small & mid-size breast while maintaining high-level of image quality

The **TiCEM dual-energy technique** provides excellent spectral separation and the comparably high X-ray yield enables consecutive examinations without tube overheating

Tomosynthesis-guided biopsy allows precise localization and targeting of suspicious tissue, the integrated specimen scanner allows instant specimen imaging

30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Thank You.
And many thanks to: Ramyar Biniazan, Axel Hebecker, Jan Korporaal,
Thomas Mertelmeier, Ralf Nanke, Marcus Radicke, Ludwig Ritschl,
Sebastian Vogt, Julia Wicklein, and many more colleagues and partners!
31
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