Multiscale phase contrast imaging in biomedical research: the experience at Elettra

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CompactLight Complementary Use and Opportunities

Synchrotron Radiation for Mammography (SYRMA) project: first clinical trial of clinical mammography

- X-ray Mammography (generally with 2 views) is the main examination used for detecting early breast cancer, widely adopted in screening programs
- It is **not enough effective** for dense breasts as lesions have similar X-ray properties of fibrous tissue

Aim : explore the potentials of phase contrast imaging on selected clinical cases
Recruitment criteria: patients whose conventional diagnosis (Rx and US) gave uncertain results.
Modality: Propagation based phase contrast planar imaging (2 projections)
Energy range: 17- 22 keV monochromatic, selected according to the breast thickness and glandularity

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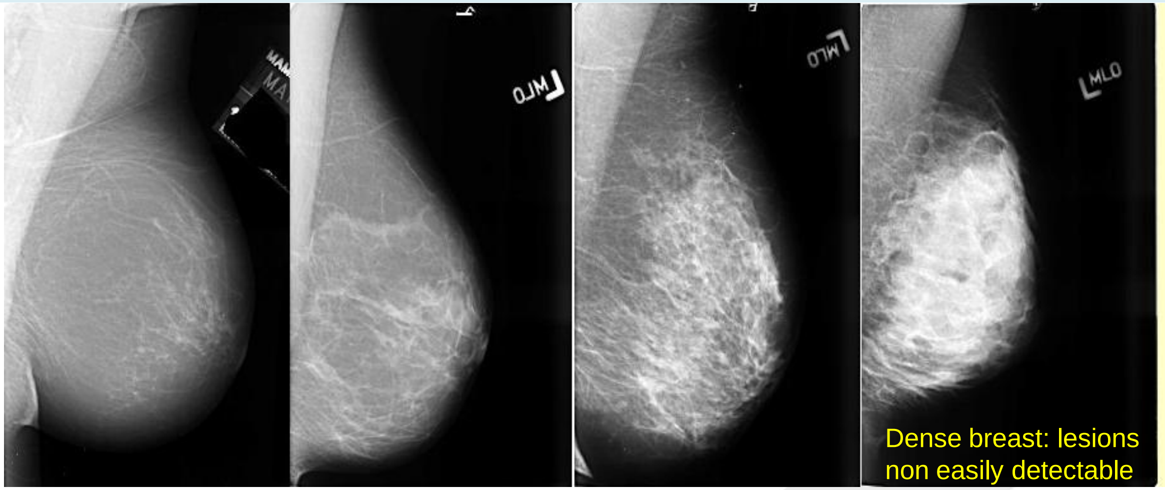

Radiographs of breasts with increasing density: mainly adipose breast (left) up to high fibro-glandularity breast (right)

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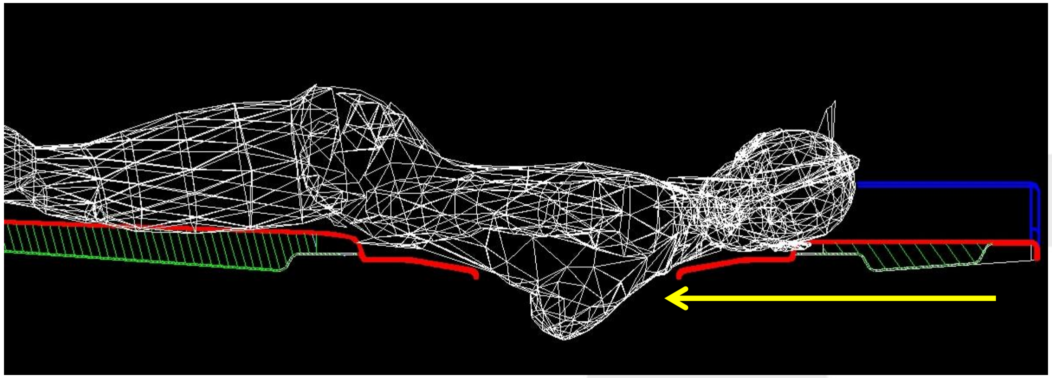
Outcomes of the first protocol

Expert radiologists compared the visibility of different features (such as lesions, calcifications, architectural distortions, focal asymmetries, etc.) in the conventional and SR images.

Exams with SR have:
- higher specificity,
- better agreement with the golden standard (biopsy),
- improved image quality,
- strong reduction of delivered doses.

The patient facility at Elettra



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E.Castelli et al.: Radiology, vol 259 (2011),
R.Longo et al., Phil. Trans. R. Soc. A 372 (2014)

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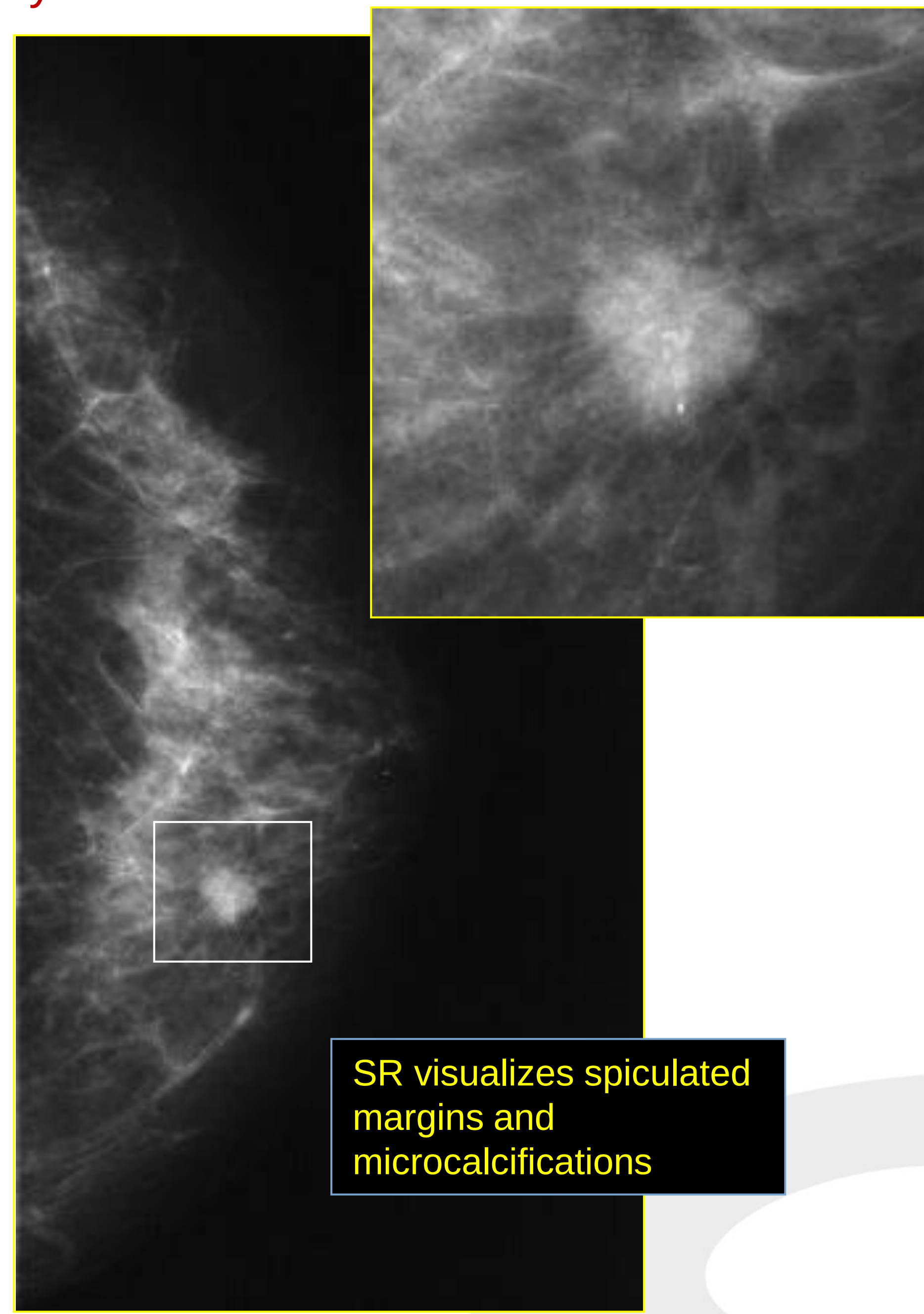
Conventional mammography

Synchrotron Radiation



E.Castelli et al.: Radiology, vol 259 (2011)

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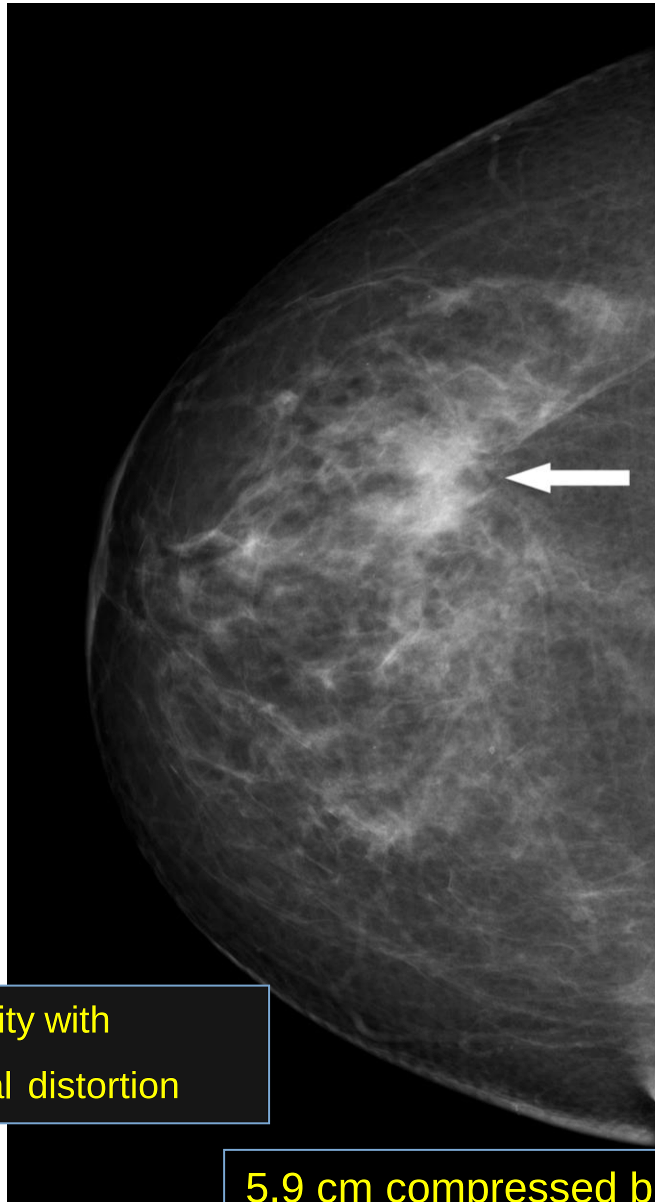
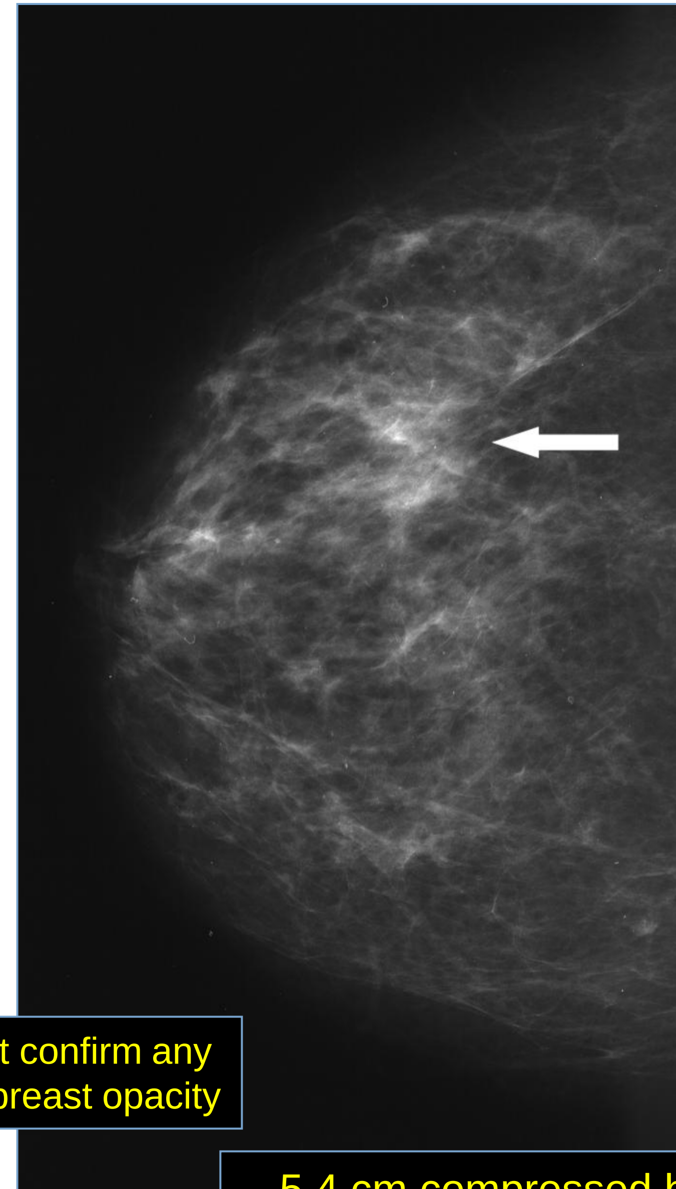
Conventional mammography



Conv: opacity with architectural distortion

5.9 cm compressed breast
29 kVp Rh/Rh
MGD 1.3 mGy

Synchrotron Radiation



SR does not confirm any suspicious breast opacity

5.4 cm compressed breast
19.5 keV
MGD 0.8 mGy

E.Castelli et al.: Radiology, vol 259 (2011)

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Towards low dose phase contrast breast CT: the SYRMA-CT project

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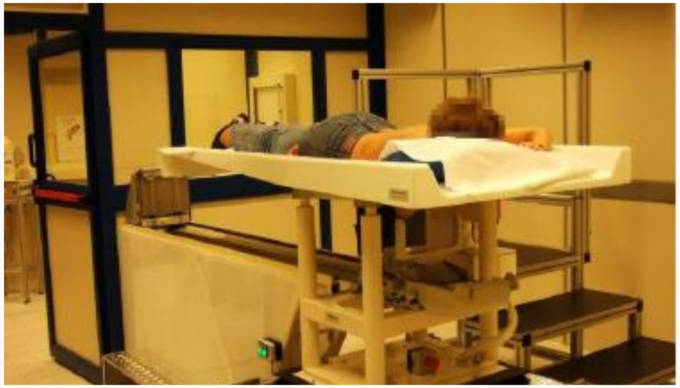
Motivations

- Projection X-ray mammography has important limitations in breast cancer detection, particularly in the dense breasts.
- 3D imaging approach implemented in additional breast imaging modalities: breast tomosynthesis, breast ultrasound, breast MRI, all used in combination.
- First dedicated breast CT systems are obtaining promising results.
- Our previous experience: SR phase contrast mammography outperforms conventional mammography

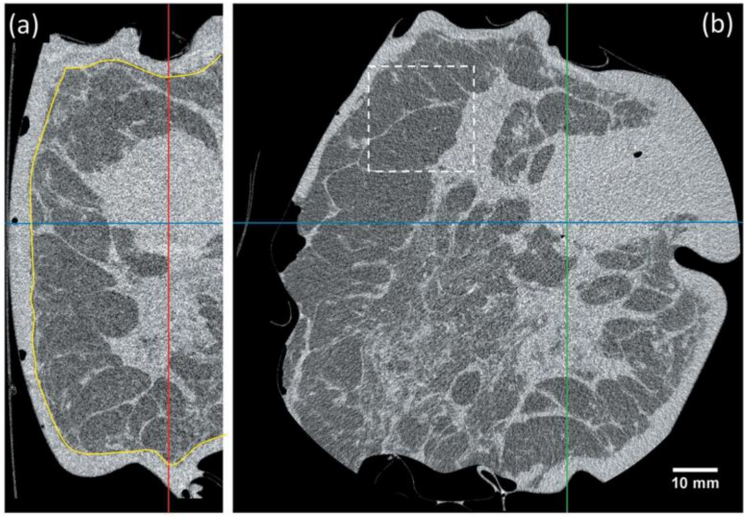


Aims

- Evaluate the effectiveness of **low dose phase contrast breast CT** on selected patients
- Reduction of Mean Glandular Dose (MGD) up to 5 or 2 mGy

Methods

- Use of sensitive Single photon counting detector (Pixirad)
- Optimization of X-ray Energy: 26-38 keV
- Application of propagation based phase contrast imaging and phase retrieval algorithms
- Optimization of reconstruction algorithms



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INFN Istituto Nazionale di Fisica Nucleare

Sezioni di: Trieste, Cagliari, Ferrara, Pisa, Napoli, Siena

R.Longo et al. :J. Synchrotron Rad. (2019). N. 26

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Low dose CT - Effect of long propagation distance

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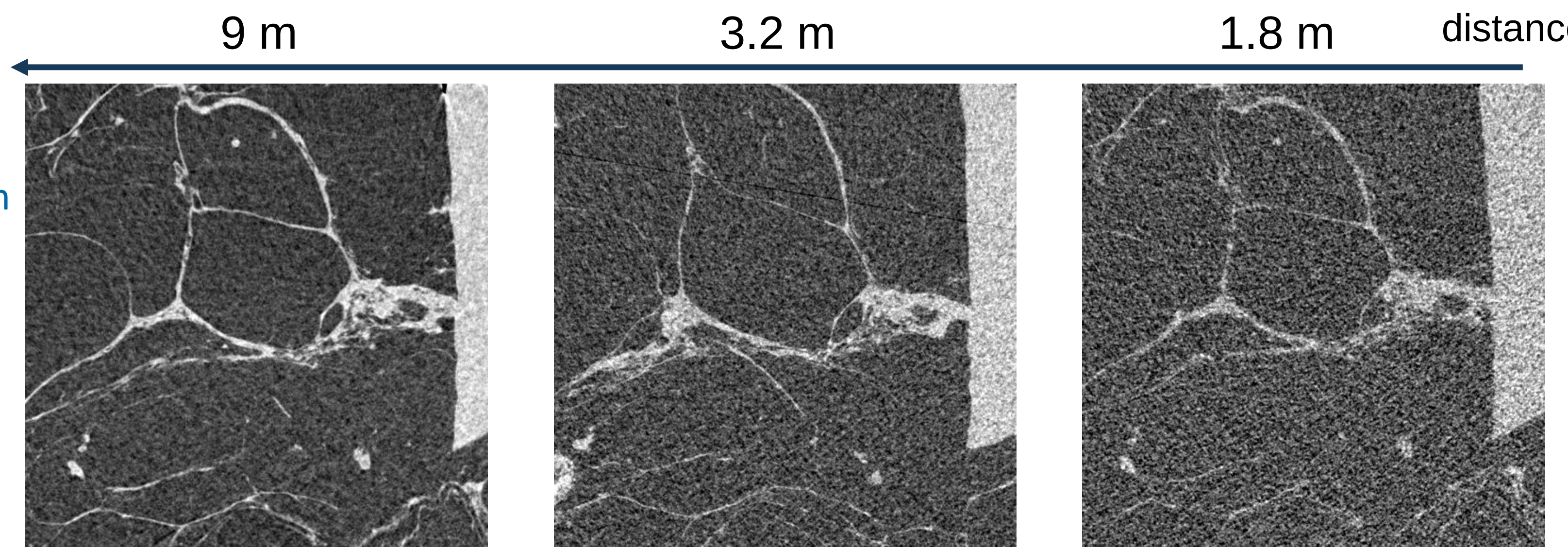
Mastectomy detail
approx. size: 1.5 x 1.5 cm
E = 32 keV
Pixirad detector
MGD ~ 5 mGy

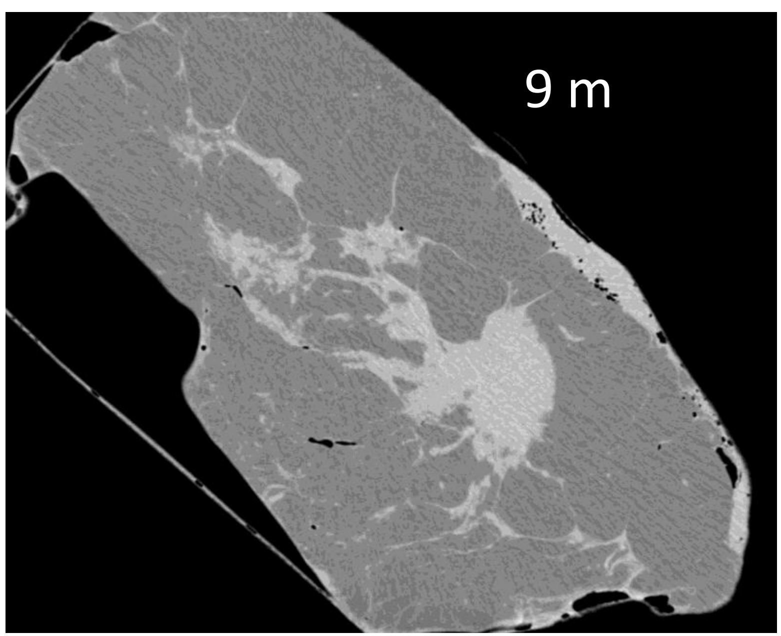
L.Brombal et al.:, Phys. Med. Biol.63, 2018

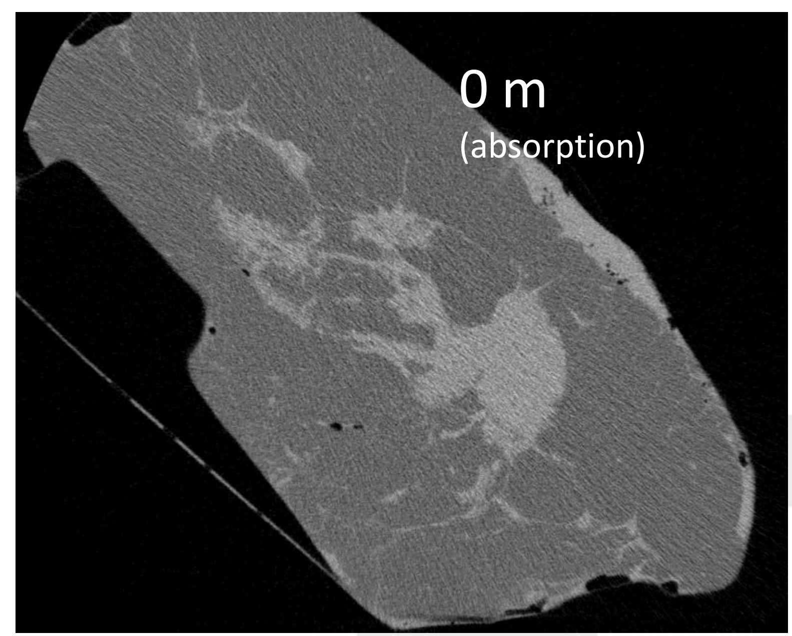


Reconstruction of low dose CT slice with application of phase retrieval algorithm (Paganin 2002)

Mastectomy slice
Size:7 x 3 cm
E = 32 keV
XCounter detector
MGD ~ 5 mGy

Baran et al.: Phys. Med. Biol. 62, 2017





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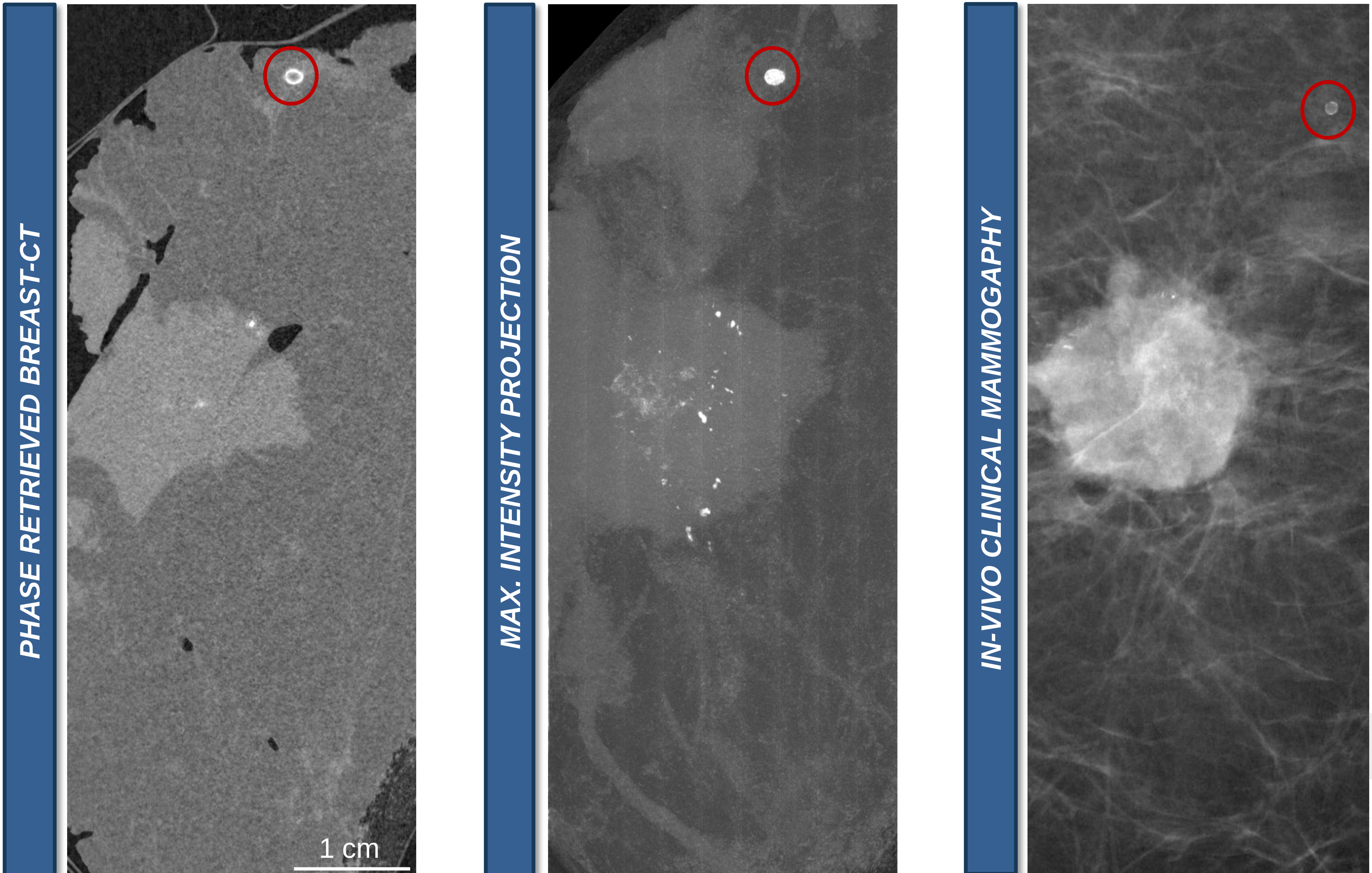
Low dose Breast CT – accurate 3D localization of microcalcifications

Tissue showing a moderate-grade infiltrating ductal carcinoma with a maximum diameter of 2.4 cm



R.Longo et al. :J. Synchrotron Rad. (2019). N. 26

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Comparison between Propagation Based-CT (PB-CT) and Dedicated Breast Cone Beam-CT (CB-CT)

Aim: to compare the diagnostic performance of two techniques for breast 3D imaging.

✓ PB-CT parameters at SYRMEP:

E = 32-40 keV, prop. distance = 9.3 m, 1800 projections over 180º

Detector used = XCounter photon counting detector (XC-FLITE FX2) with a pixel size of 100 µm

Data processing: phase retrieval (Paganin et al., 2002) and CT FBP reconstruction.

Mean Glandular Dose = 5 mGy

✓ CB-CT parameters:

Koning Breast-CT system (x-ray tube with a 0.3 mm focal spot size).

Operation parameters: 49 kVp, 120 mAs, 360º rotation

Detector used: flat panel with a pixel size of 273 µm

Mean Glandular dose = 5.8 mGy

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S.Pacilè et al., Scientific Reports | (2019) 9:13762

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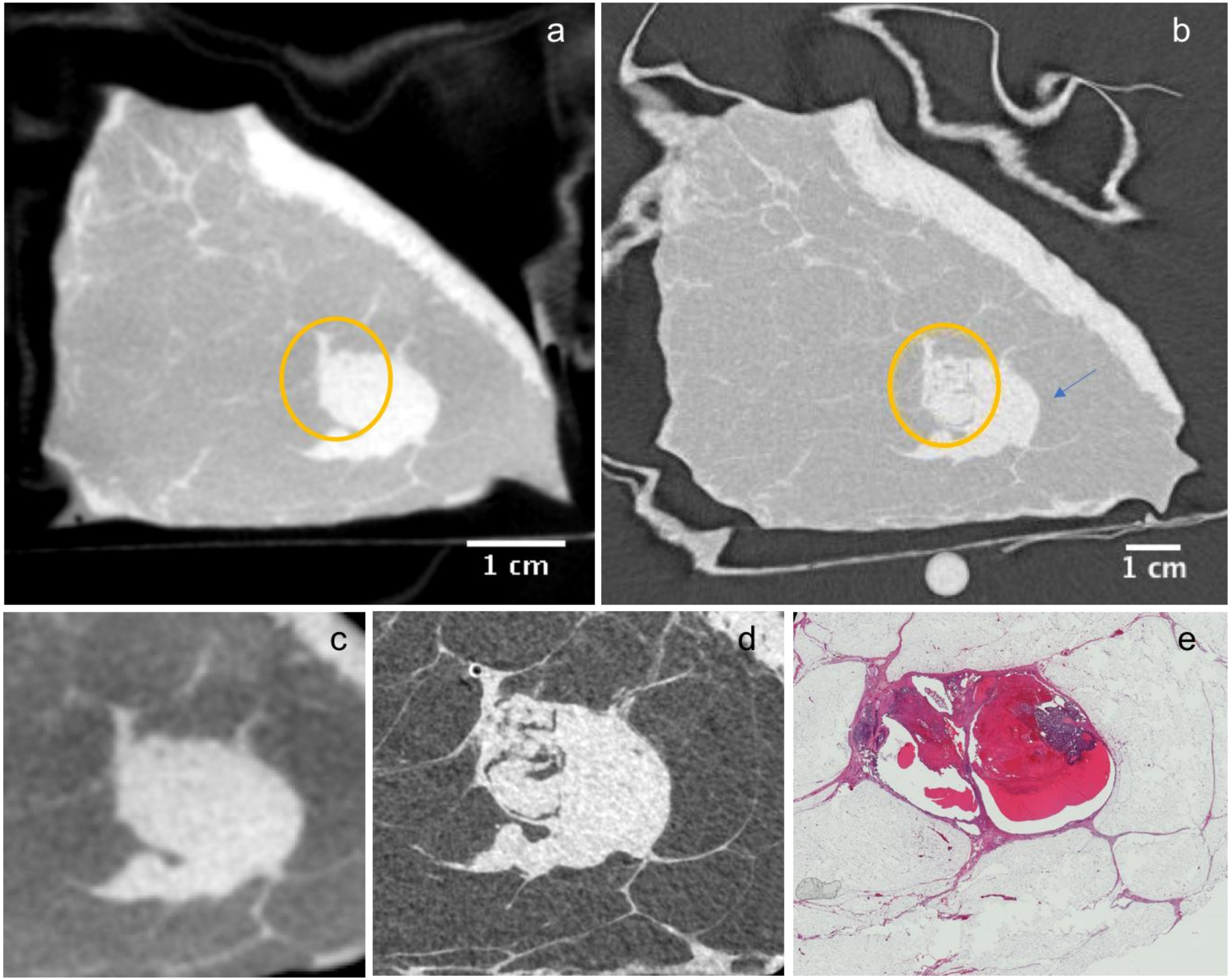
Comparison between PB-CT and CB-CT

Conventional — Synchrotron



Excised breast sample including an *in situ* intraductal papillary carcinoma.

a) image obtained with the dedicated CB-CT system (Konig).
b) image obtained with PB-CT technique.

The blue arrow indicates the part of the lesion with regular borders, the yellow circle highlights the infiltrating part.

c) Close-up CB-CT
d) Close-up PB-CT
e) Histological Image

S.Pacilè et al., Scientific Reports | (2019) 9:13762

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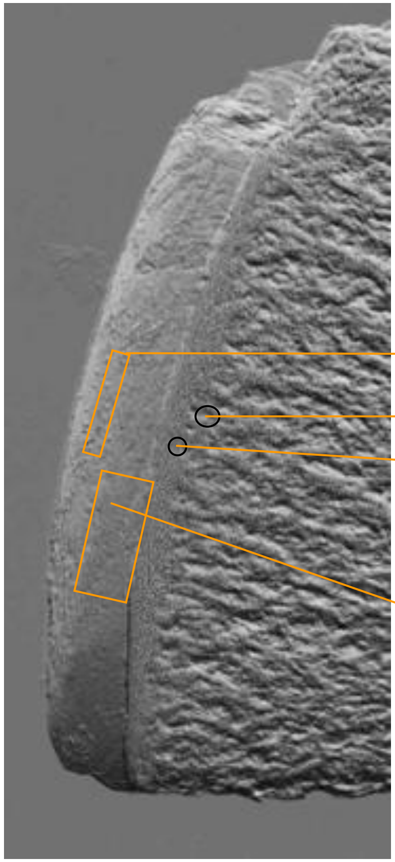
Studies of Cartilage and bone interface

Osteoarthrosis (OA) is a disease characterized by the progressive degeneration of articular cartilage. It has a high incidence in the adult population. Affecting mainly the elderly population, it is one of the main causes of disability worldwide. Conventional radiography detects only **important osseous changes**, at advanced stages of disease, when therapeutic strategies are less effective. **Early changes** in the **cartilage** and other **articular tissues** are **not** directly visible. MRI imaging works better but the maximum achievable spatial resolution is not always adequate.

Need to study:
- cartilage
- cartilage-bone interfaces
- changes in the bone structure

Aim: detect the architectural arrangement of collagen within cartilage and evaluate how the cartilage degeneration affects the underlying subchondral and trabecular bone.



Superficial Layer (Zone of horizontal collagen fibers with flat cells)

Subchondral Bone Plate (**Important for diagnostic purposes in OA**)

Tidemark (Border between normal and mineralized cartilage)

Transitional and Deep Layer (round cells, collagen fiber switches from horizontal to vertical orientation, increasing stiffness and material density)

Visualization of a human femur head

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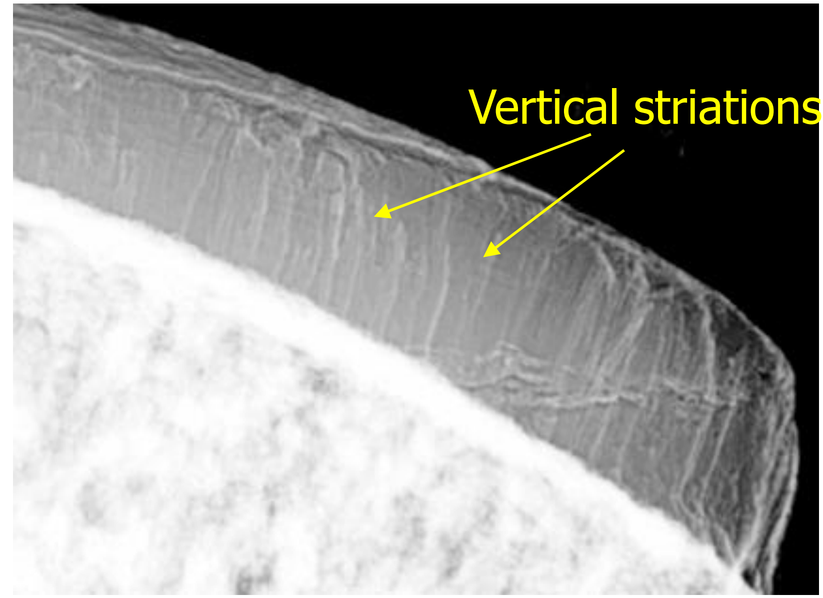
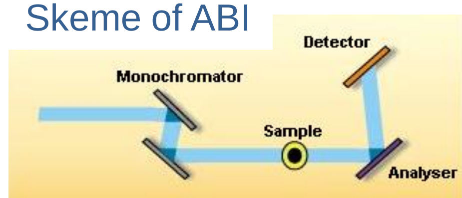
- The Analyzer Based Imaging (ABI) technique allows to visualize the discontinuities in the sample and the inner structures invisibles by means of conventional imaging.
- The transition bone-cartilage is emphasized.
- The articular cartilage striations are well visible due to X-ray diffraction at edges of fibers

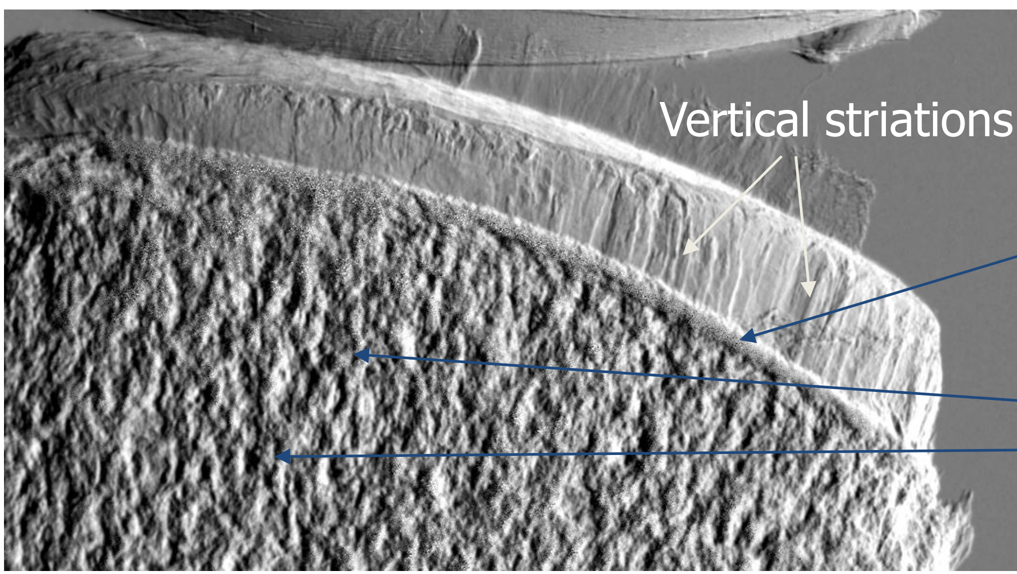


Apparent absorption image

Skeme of ABI



Refraction image



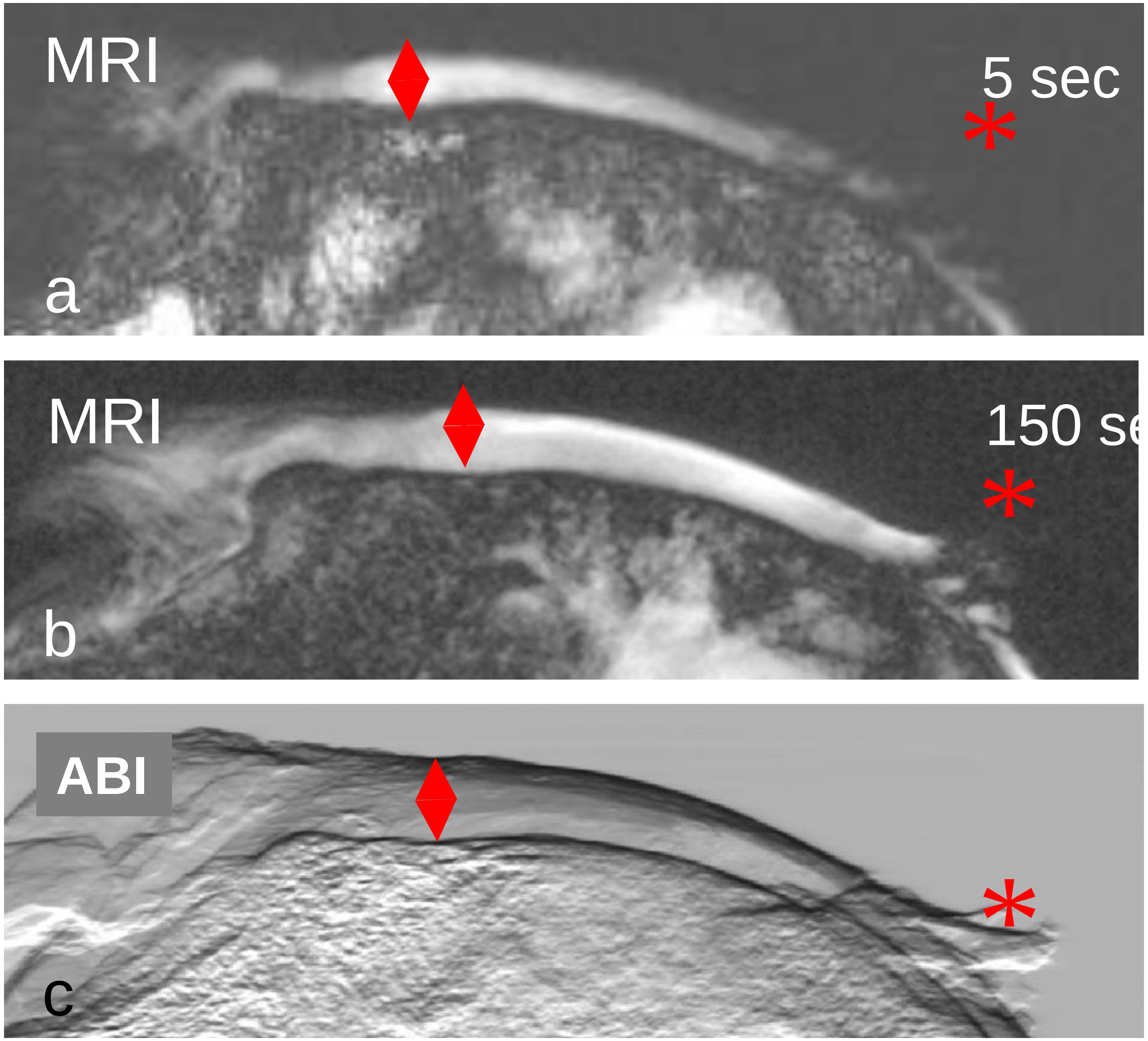
Subchondral bone

Trabecular bone

Elettra
25 keV

Muehleman C et al., J, Osteoarthritis and Cartilage 12 (2): 97-105, 2004

Femur head core cuts: comparison with MRI



A.Wagner et al., Nucl. Instrum. Methods A 548, 47 (2005).

Key parameters and fluxes requirements

	High resolution (virtual histology)	Tissues imaging/small animals	Clinical Breast imaging	Clinical Lung CT	Clinical Cartilages
Sample horiz size	1 - 20 mm	10 – 50 mm	6 - 15 cm	> 30 cm (Local Area)	8 - 15 cm
Sample thickness	1 - 10 mm	10 - 150 mm	6 - 15 cm	> 25 cm	6 - 10 cm
Pixel size (μm)	0.3 - 4	9 - 50 (in-vivo)	50 – 60	100	30-50
Energy range (keV)	**8 – 40**	**17 – 30**	**17 -22** (2D imaging) **30 - 40** (CT)	**40 – 60**	**22 - 30**
Energy resolution	large bandwidth acceptable	low Δ E/E required with contrast agents	large bandwidth acceptable	large bandwidth acceptable	low Δ E/E required with ABI technique
Flux (min req)	10^{10} - 10^{12} ph/mm²/s	5 10^{7}- 10^{8} ph/mm²/s	10^{8} ph/mm²/s	10^{8} ph/mm²/s	5 10^{7}- 10^{8} ph/mm²/s
Typical time for each CT scan	some sec to some mins (according to the available flux)	some sec to some mins (for in-vitro), 10 s or more for CT, according to acquisition mode	1-2 s for planar scan, 10 - 20 s for CT	1-2 s for planar scan, 10 s for CT (breath hold)	1-2 s for planar scan, 10 - 60 s for CT
Acquisition modality for CT	free running	Free running (breath hold) or retrospective gating or perspective gating	free running	Free running (breath hold) or perspective gating	free running

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Acknowledgements

D.Dreossi, L.Mancini, N.Sodini,– Elettra Sincrotrone Trieste
F.Arfelli, L. Brombal, R.Longo, L. Arana Pena, L.Rigon - Dept of Physics – Univ. of Trieste and INFN
D.Bonazza, M.Bortul, M.A.Cova, M.Tonutti, F.Zanconati – Cattinara University Hospital, Trieste

S.Mayo, Y.Nesterev – CSIRO, Australian Synchrotron, Melbourne
T.Gureyev, - University of Melbourne
P.Brennan – University of Sydney

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Thanks for your attention!

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