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2013 will be a fundamental year for X-ray imaging at the ESRF. Work will continue for the phase I projects of UPBL4-NINA and the ID19/ID17/paleontology refurbishment with various steps of implementation and commissioning being scheduled. Discussions will also start regarding phase II.
While phase I was oriented towards improved resolution (in particular nanoscopy), phase II could be the opportunity to explore temporal resolution. Hence the name of the workshop, satellite to the 2013 Users meeting: "X-ray cinematography with the new coherent source".

M. Cotte

Fig. 55: 3-D imaging of various developmental stages of Nile crocodile embryos *in ovo* (from la Ferme aux crocodiles, Pierrelatte, France) using long distance propagation phase contrast tomography at beamline ID19. In addition to the skeleton development highlighted here, this approach allows the anatomy of the soft tissue to be visualised. These samples were studied within a research project on archosaur phylogeny (crocodiles, dinosaurs, birds). By studying the embryological development of modern crocodiles and birds, it is possible to derive information to better understand the evolutionary transition from dinosaurs to birds. Credits: Martin Kundrát (Uppsala University) / Paul Tafforeau (ESRF).

Towards reduced radiation dose for 3-D breast cancer scans

Early detection of breast cancer contributes to an improved prognosis and results in reduced disease mortality. The breast cancer screening technique used today in clinics is "dual-view digital mammography". Its limitation is that it only provides two images of the breast, which can explain why up to 20% of breast tumours are not detectable on mammograms. Mammograms can also sometimes appear abnormal, when no breast cancers are actually present. Computed tomography (CT) allows a precise 3-D visualisation of the human body but it cannot be routinely applied in breast cancer diagnosis because of the high radiosensitivity of the breast, which significantly reduces the benefit-risk ratio. The potential induction of tumours due to the exam itself is considered too high. Recognising these limitations, we have developed a way to produce three-dimensional X-ray images of the breast at a radiation dose that is lower than the 2D radiographies used in clinics. Phase contrast X-ray tomography at 60 keV of a whole human breast has been performed at **ID17**. Images were reconstructed applying the so-called "equally sloped tomography" (EST) algorithm using 512 projections to produce 3-D images of the organ at a resolution higher than that used in clinical CT (pixel size of 92 µm vs more than 200 µm for clinical CT scanners) and at a lower dose than that of dual view mammography (which is typically about 3 mGy). The new method allows a clear and precise identification of a malignant cancer. According to a blind evaluation by five experienced radiologists, this method can reduce the radiation dose and acquisition time by ~74% relative

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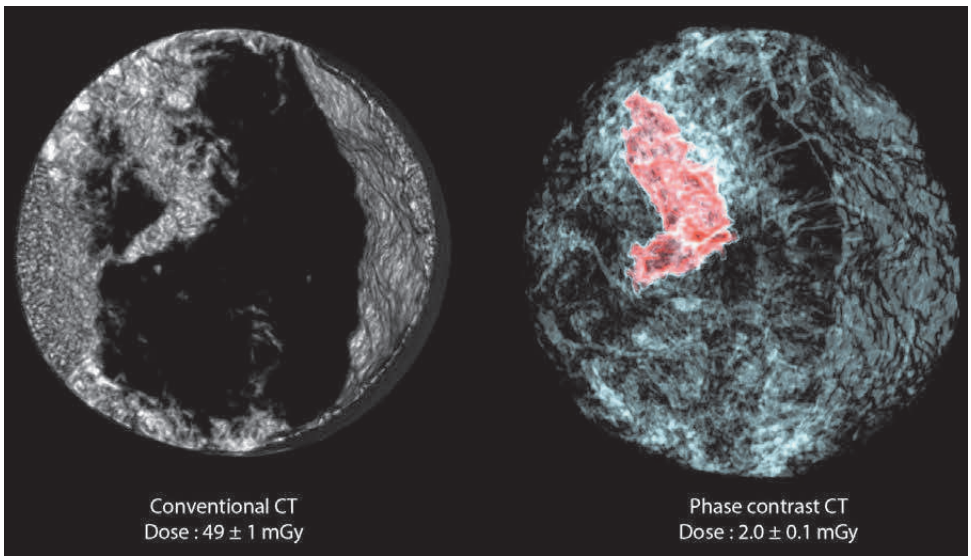

Fig. 56: Comparison between a conventional CT scan of the breast sample and a scan using EST with phase contrast imaging. In the latter image, the tumour is highlighted in red. The radiation dose needed for the scans is indicated at the bottom.

to conventional phase-contrast X-ray tomography, while maintaining high resolution and contrast. Despite the significant reduction in the number of projections used (corresponding to an important saving in dose and acquisition time), radiologists ranked the generated images as having the highest sharpness, contrast, and overall image quality compared to 3-D images of breast tissue created through other standard methods (based on the filtered back projection algorithm (FBP)) (**Figure 56**).

CT scans for early detection of breast cancer may now become possible thanks to the combination of three ingredients: high energy X-rays, phase contrast imaging and the use of a sophisticated novel mathematical algorithm, the EST, to reconstruct the CT images from X-ray data. Tissues are more transparent to high energy X-rays and therefore less dose is deposited (a factor of 6 in radiation dose reduction). The phase contrast imaging technique may allow contrast to be observed due to the phase modulation of X-rays, even if the amplitude (*i.e.* absorption) modulation is weak or absent, with a dose to the tissues similar or even reduced compared to conventional absorption radiography. Finally, the EST method is a Fourier-based iterative method that iterates back and forth between real and Fourier space using the pseudo-polar fast Fourier transform. At each iteration, physical constraints, including the sample boundary and the non-negativity of the sample structure, are enforced in real space, while the Fourier transform of the measured projections are imposed in Fourier space. As a result, the EST needs 4 times less radiation than FBP to produce images of the same quality (**Figure 57**).

It was therefore demonstrated that diagnostic CT images can be produced with a spatial resolution 2-3 times higher than present hospital scanners, but with a radiation dose that is about 25 times lower. This new technique can open the doors to the clinical use of CT in mamography, which would be a powerful tool in the fight against breast cancer.

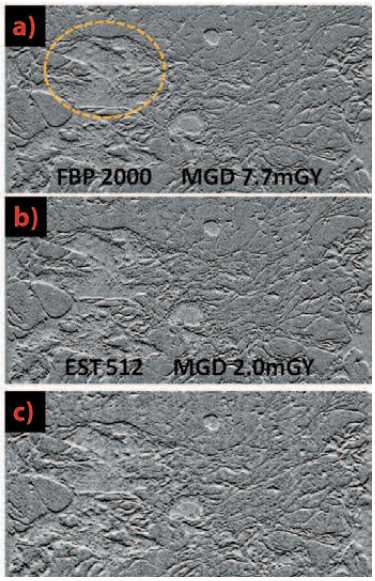

Fig. 57: Image quality comparison of the phase contrast CT images of the whole breast (9 cm diameter), reconstructed using the conventional (Hamming filtered) FBP algorithm or the EST. a) A 92-µm-thick sagittal slice of the FBP reconstruction using 2000 projections, b) EST using 512 projections or c) EST 200. The yellow ellipse indicates a tumour region. FBP 2000 and EST 512 have the highest image quality, EST 200 (with 1/10 of the dose necessary to reconstruct the FBP2000) still shows a high contrast.