Principles of and Requirements for X-Ray Fluorescence Imaging (XFI)

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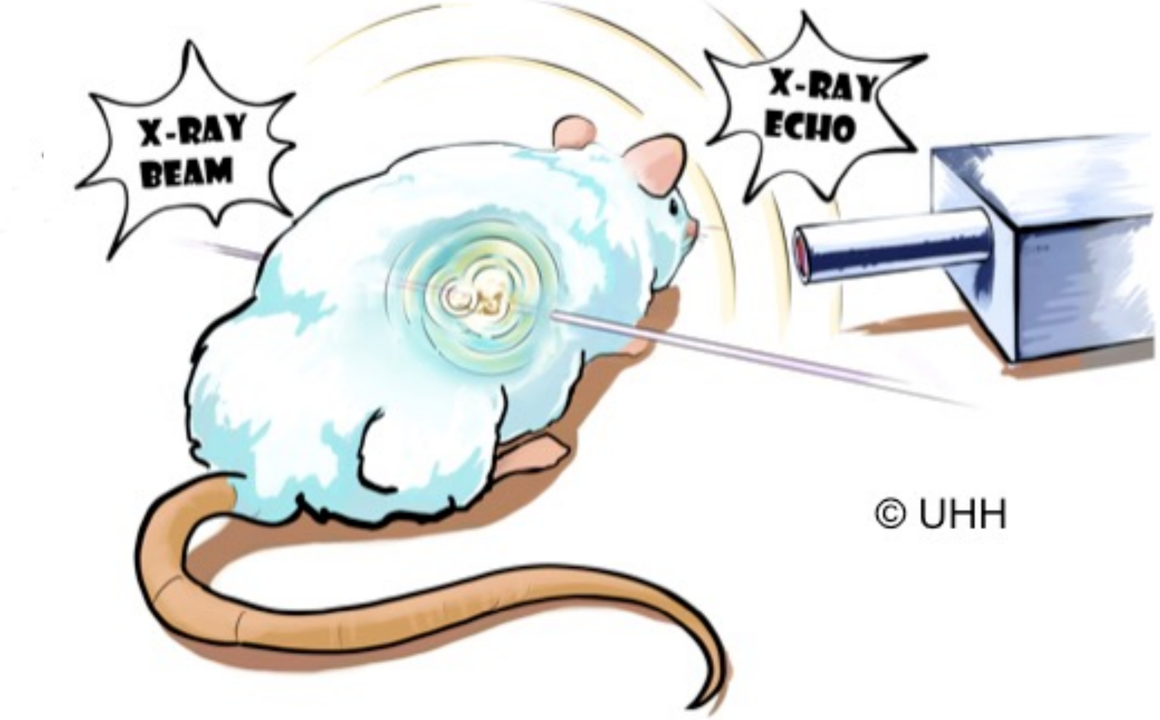
Outline

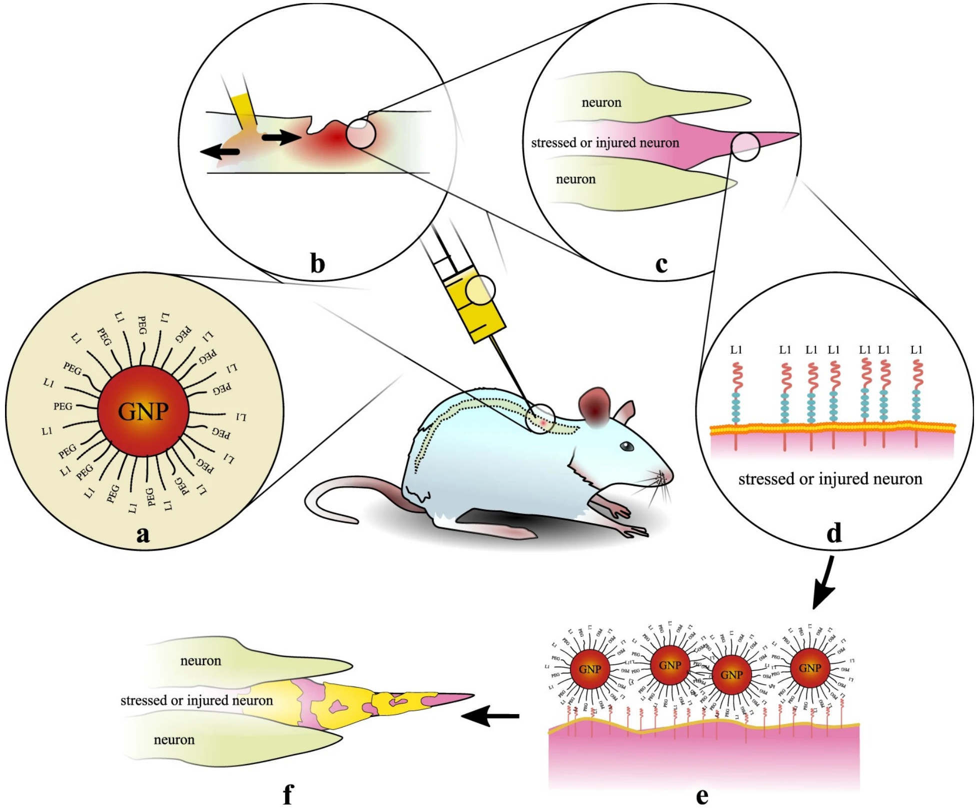
- Why use XFI?
- Principles of XFI
- Requirements on detectors
- Preclinical R&D goals



Why XFI?

- Possibility to label different entities
  - →immune cells
  - →medical drug compounds
  - →Functionalized nanoparticles
  - →antibodies
  - →Micro- and nanoplastics

→ applications in medical diagnostics or pharmacokinetics

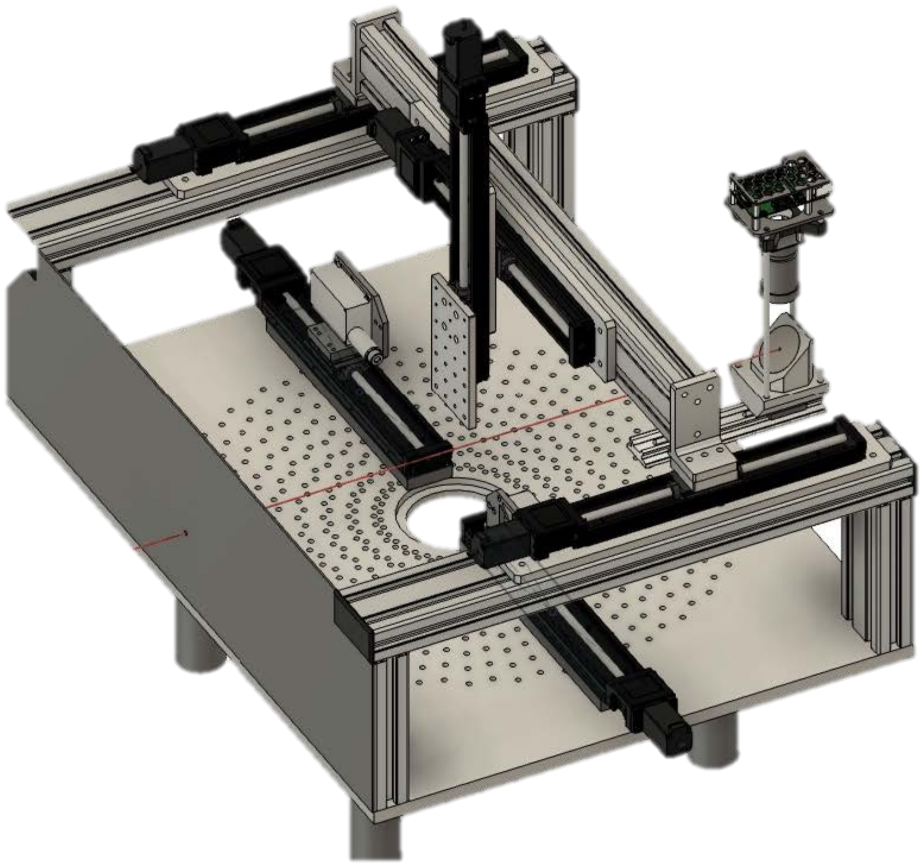


F. Grüner et al., Sci. Rep. 8, 1656 (2018)

Principles of XFI

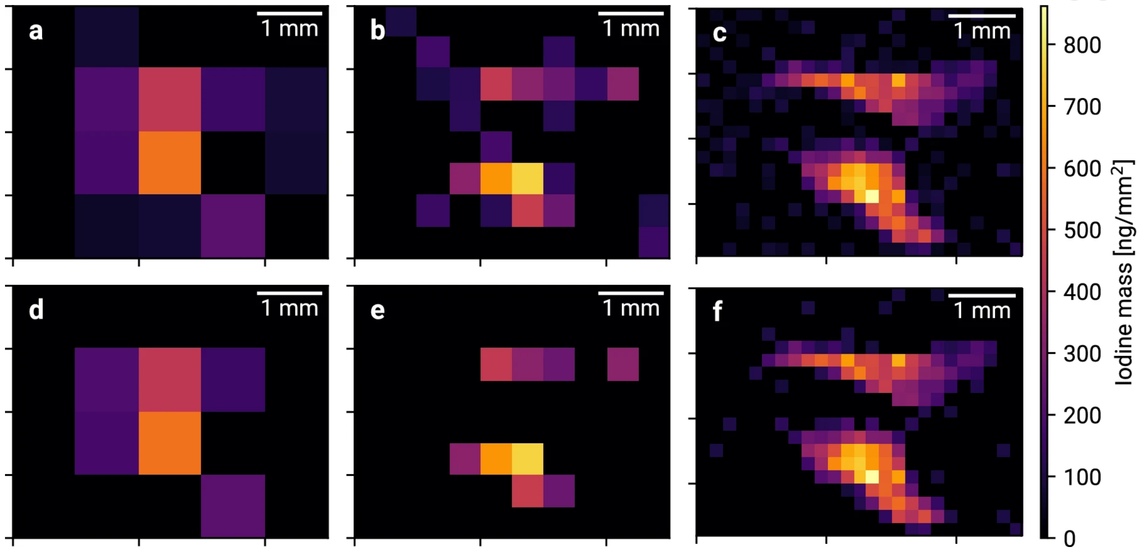
- Pencil X-ray beam scans object
- Excitation of characteristic fluorescence
- Resulting fluorescence can be detected

→ determine absolute amount and location of tracer

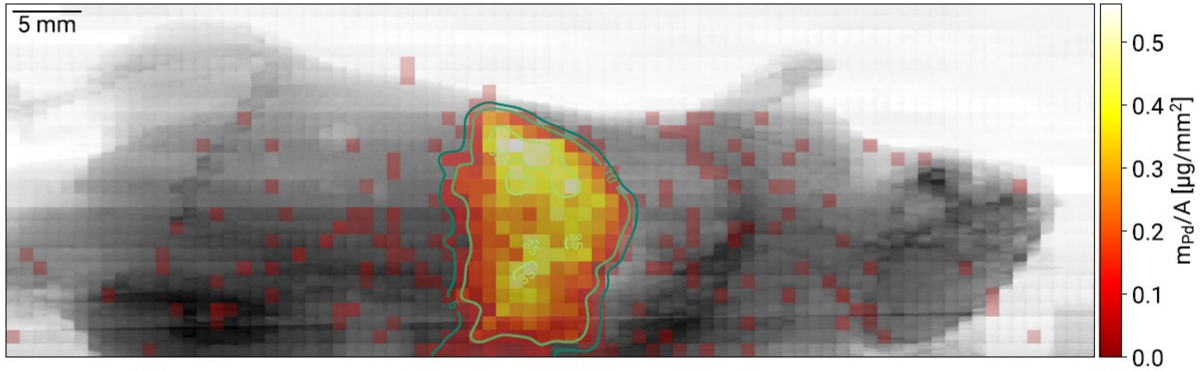


Added values of XFI

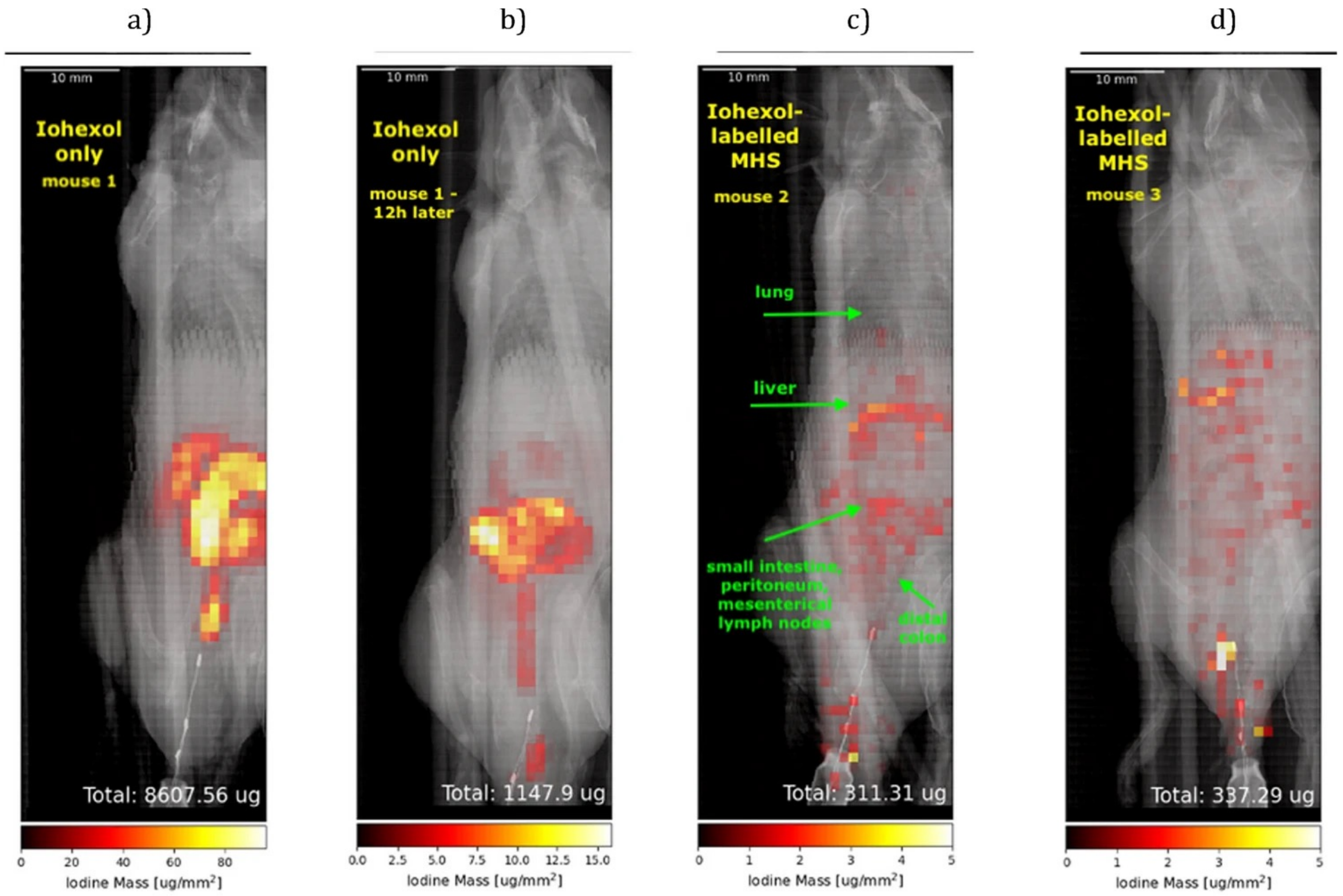
- Non-invasive
- High sensitivity
- High spatial resolution
- Longitudinal studies
- Multi-tracking
- Multi-scale imaging



C. Körnig et al., Sci. Rep. 12, 2903 (2022)



XFI-example: in-vivo cell tracking



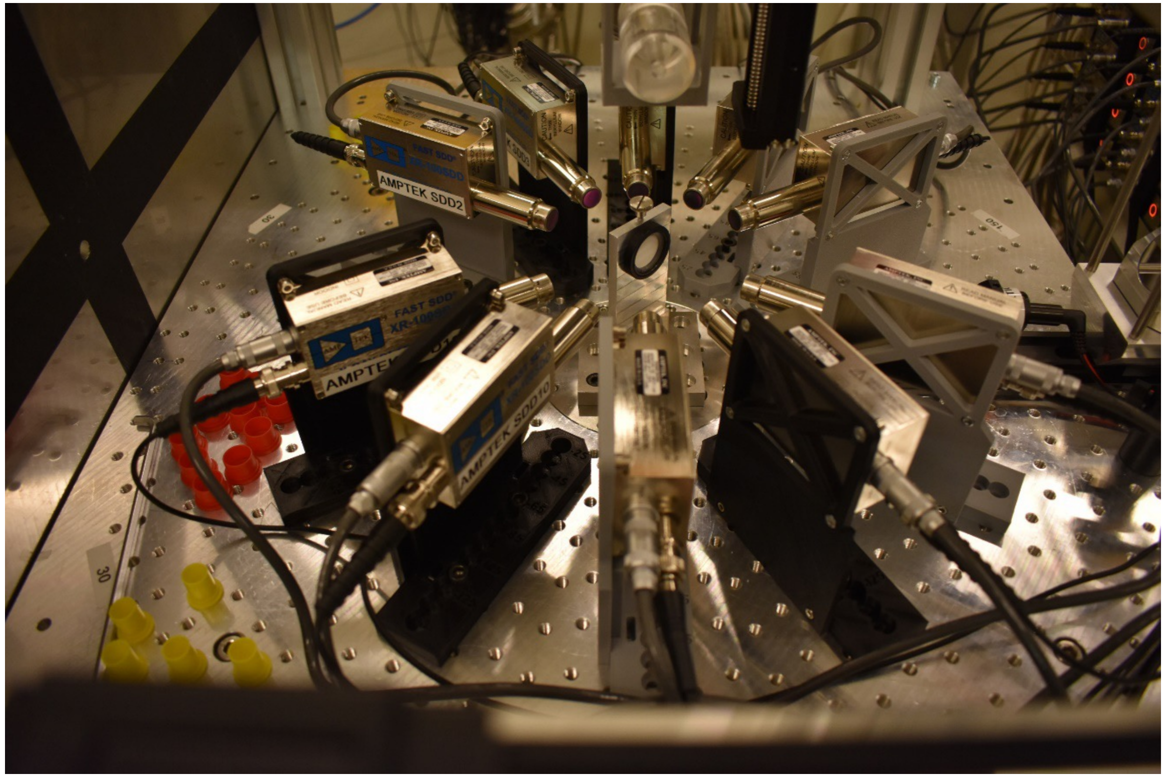
T. Staufer et al., Sci. Rep. 13, 11505 (2023)

Our experiences with High-Z detectors

- Used CdTe and Si-PIN detectors for multiple XFI measurements with different tracers
- Proof-of-principle XFI measurements at a Thomson source with a HEXITEC detector
- Extensive work on calibration using radioactive sources
- Spatial reconstruction in XFI-measurements using pixelated detectors

Requirements on detectors

- Good energy resolution (≤ 1 keV FWHM at 60 keV)
- High efficiency
- Large active area
- Little intrinsic detector effects
- High count rate capability



Preclinical R&D goals

- Pharmacokinetics
  → tracking of medical drugs (in vivo)
- In vivo – tracking of immune cells
- Tracking of nano- and microplastic particles

Detectors:

- Increase number of detectors
- Use multiple or pixelated detectors to cover a larger area

Publications by UHH-Team on XFI

- Florian Grüner et al. “Localising functionalised gold-nanoparticles in murine spinal cords by X-ray fluorescence imaging and background-reduction through spatial filtering for human-sized objects”, *Scientific Reports*, Volume 8, Issue 1, Article number 16561 (**2018**)
- Carlos Sanchez-Cano et al. “X-ray-Based Techniques to Study the Nano–Bio Interface”, *ACS Nano* **2021**, 15, 3754−3807
- Oliver Schmutzler et al. “X-ray Fluorescence Uptake Measurement of Functionalized Gold Nanoparticles in Tumor Cell Microsamples”, *Int. J. Mol. Sci*. **2021**, 22, 3691
- Henrik Kahl et al. ”Feasibility of Monitoring Tumor Response by Tracking Nanoparticle-Labelled T Cells Using X-ray Fluorescence Imaging—A Numerical Study”, *Int. J. Mol. Sci*. **2021**, 22, 8736.
- A. Ungerer et al. "X-ray-Fluorescence Imaging for In Vivo Detection of Gold-Nanoparticle-Labeled Immune Cells: A GEANT4 Based Feasibility Study", *Cancers* **2021**, 13(22):5759
- C. Körnig et al. " In-situ X-ray fluorescence imaging of the endogenous iodine distribution in murine thyroids“, *Scientific Reports* 12, 2903, **2022**
- J. Baumann et al. “Enabling Coarse X-ray Fluorescence Imaging Scans with Enlarged Synchrotron Beam by Means of Mosaic Crystal Defocusing Optics“, *Int. J. Mol. Sci.* **2022**, *23*(9), 4673
- T. Staufer, M.L. Schulze, O. Schmutzler et al. “Assessing Cellular Uptake of Exogenous Coenzyme Q_{10} into Human Skin Cells by X-ray Fluorescence Imaging“, *Antioxidants* 11, no. 8:1532, **2022**
- Y. Liu et al. “Size- and Ligand-Dependent Transport of Nanoparticles in *Matricaria chamomilla* as Demonstrated by Mass Spectroscopy and X-ray Fluorescence Imaging”, *ACS Nano,* **2022**
- T. Staufer et al. “Enabling X-ray fluorescence imaging for in vivo immune cell tracking”, *Scientific Reports* 13, 11505, **2023**
- T. Staufer and F. Grüner “Review of Development and Recent Advances in Biomedical X-ray Fluorescence Imaging”, *Int. J. Mol. Sci*. **2023**, 24(13):10990

Our UHH-XFI-Team