# DARK-FIELD IMAGING FOR DENTAL PATHOLOGIES

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Dark-field imaging is a new and promising X-ray imaging modality in wich contrast comes from X-ray scattering caused by small structures in the sample. This modality therefore provides information at dimensions smaller than the pixel size, unresolved by conventional X-ray imaging.

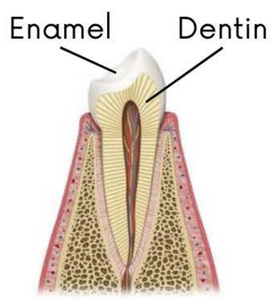
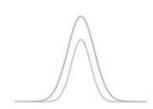
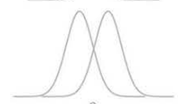



Fig 1 : Tooth schematic

In this context, **dark-field imaging** can be an effective tool to study **dental pathologies**, in particular, **dentin damage** (Fig 1). Dentin tubules are composed of mineralized collagen fibers arranged periodically with a pitch of 68 nm and can be altered in the case of oral inflammatory diseases [1].

In this study, dark-field imaging was successfully implemented on human teeth, providing **quantitative information** on dentin and its structure that is not accessible in conventional radiography.

The attenuation signal can be decomposed into 3 components of imaging interest

| X ray interaction | | Retrieved information |
|---|---|---|
| Absorption |  | Absorption |
| Refraction |  | Phase |
| Scattering |  | Dark-field |

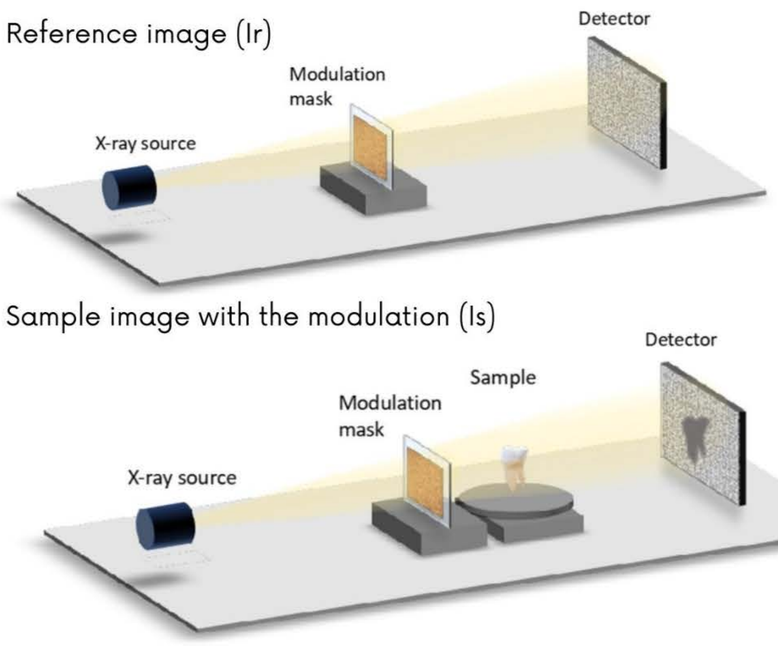
## METHOD

Human teeth were imaged at the ESRF synchrotron and on a low-coherence laboratory instrument developed by Xenocs SAS, using the Modulation Based Imaging (MoBI) method to obtain dark-field images.

**MoBI method** : Acquisition of images of a reference pattern with and without the presence of the sample. The sample induces distortions in the reference that are used to digitally reconstruct absorption, phase and dark-field images.

VIDEO OF THE MoBI METHOD HERE !

### 1. Reference and sample images




### 2. Numerical processing

Reconstruction of absorption, phase and dark-field images using 2 algorithms :

- **For coherent source** (ESRF) : Multimodal intrinsic speckle-tracking (MIST) [2].
- **For low coherence set-up** (Xenocs device) : Low Coherence System (LCS) [3] :

Ir and Is images processed by the LCS algorithm that solves the optical flow conservation equations :

$$I_r(x,y) - \frac{I_s(x,y)}{I_{obj}(x,y)} \simeq D_x(x,y)\frac{\partial Ir(x,y)}{\partial x} + D_y(x,y)\frac{\partial Ir(x,y)}{\partial y} - dD_f(x,y)\nabla_\perp^2[I_r(x,y)]$$

Absorption | Phase | Dark-field

**Directionnal dark-field** can also be retrieved developing the **dark-field** term as a tensor that describes the scattering orientation.

## RESULTS

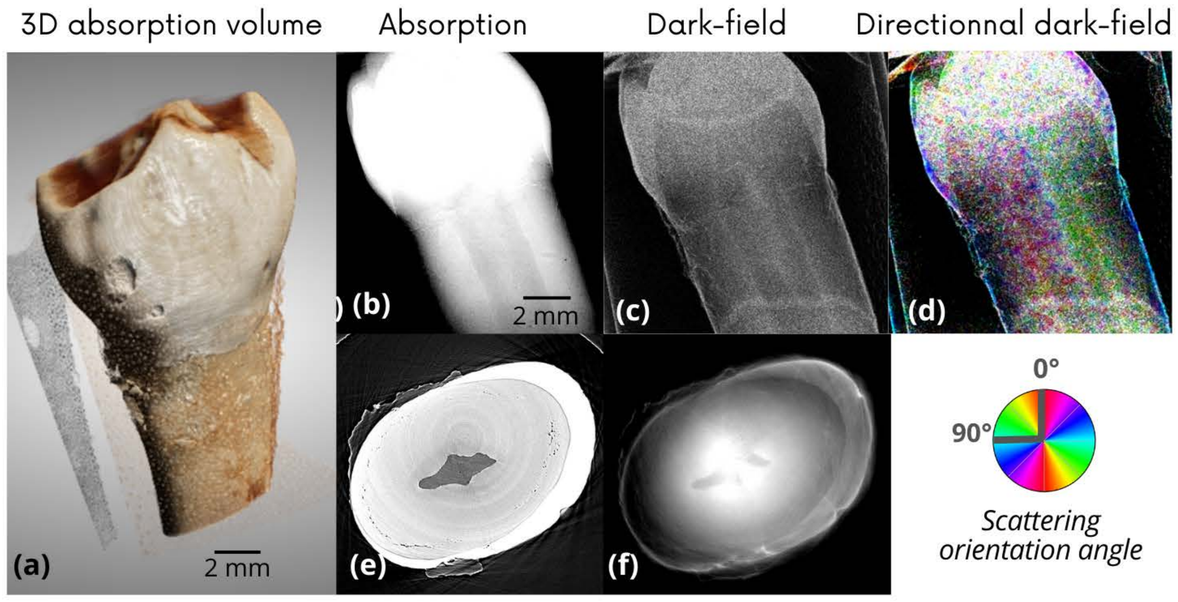



Fig 2 : 3D volume reconstruction of the tooth in attenuation tomography (a). Radiography projection (b) and slice (e). Dark-field projection (c) and slice (f) that maps the dentinal tubules (100 times smaller than the pixel size of 13 µm) and directional dark-field (d) that shows the orientation of these collagen fibers.

Dentin tubular structures are not visible in radiography (b, e) even at high resolution.

The dark-field image (c, f) shows a strong signal in the dentin tubules area. The intensity of this signal is related to the number of collagen nanostructures in the sample.

Directional dark-field (d) provides quantitative information on the orientation of dentin tubules (perpendicular to the scattering direction).

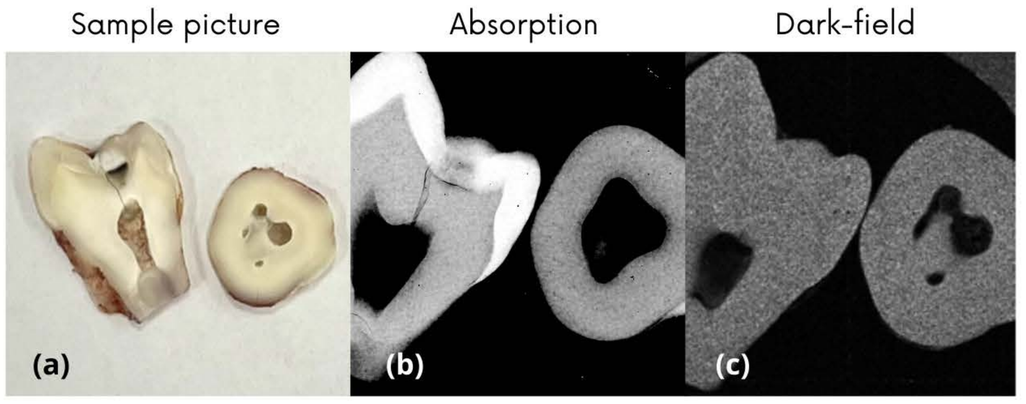



Fig 3: Picture of the 1 mm tooth slices (a). X-ray radiography (b) and dark-field image (c) of the sample obtained on the low coherence Xeuss device at 1 m propagation distance, with a pixel size of 75 µm and at a mean energy of 8.6 keV.

**REFERENCES :**

**[1]** Kovacs CS, Chaussain C, Osdoby P, Brandi ML, Clarke B, Thakker RV. The role of biomineralization in disorders of skeletal development and tooth formation. Nat Rev Endocrinol. 2021 Jun;17(6):336-349.

**[2]** Alloo, S.J., Morgan, K.S., Paganin, D.M. et al. Multimodal intrinsic speckle-tracking (MIST) to extract images of rapidly-varying diffuse X-ray dark-field. Sci Rep 13, 5424 (2023)

**[3]** C. Magnin, L. Quénot, et al. Dark-field and directional dark-field on low-coherence x ray sources with random mask modulations: validation with SAXS anisotropy measurements, Opt. Lett. 48, 5839-5842 (2023) .

Successful translation of dark-field imaging using a low coherence source.

Very strong signal of dark-field is obtained in tooth slices (c).

Optimization of the set-up in progress (propagation distance, energy...) for a clinical implementation.