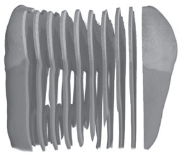
Nano-Imaging in Dentistry

Hans Deyhle[1,2], Oliver Bunk[1] and Bert Müller[2]

[1]Swiss Light Source, Paul Scherrer Institut, 5232 Villigen, Switzerland
[2]Biomaterials Science Center, University of Basel, c/o University Hospital, 4031 Basel, Switzerland

INTRODUCTION



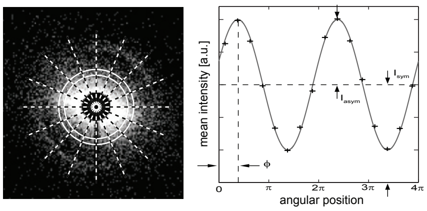
Nanodentistry deals with the prevention, diagnosis and treatment of oral diseases by applying materials tailored on the nanometer level. For any of these techniques to be effective, a deep understanding of the tissue of concern is needed. Imaging techniques routinely used in clinical dentistry and dental research, are mainly low resolution large field of view (FOV) techniques, such as computed tomography (CT), or high resolution low FOV techniques as scanning electron microscopy (SEM).

Exploiting the high brilliance of synchrotron facilities, scattering experiments in a scanning setup recently became available. In this setup, the specimen is scanned through a focused X-ray beam in steps of several micrometers, thus providing the means to scan macroscopic areas with micrometer resolution in reasonable time.

SPECIMEN PREPARATION

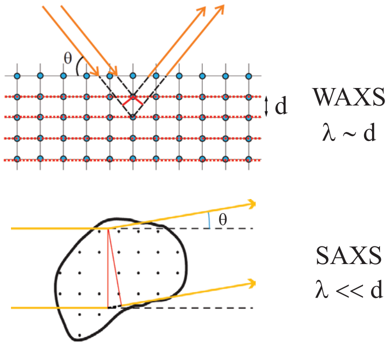
Human molars, extracted for clinical reasons, were cut into 200 to 500 µm thin slices orthogonal and parallel to the tooth axis. The tooth slices were scanned at the cSAXS beamline in SAXS and WAXS setup, respectively, see to the right.

DATA PROCESSING

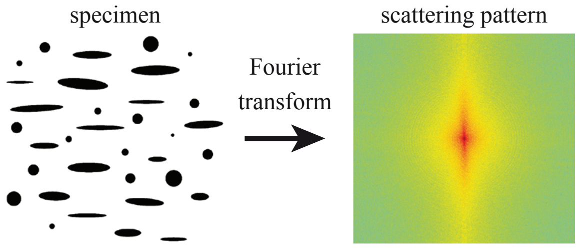


The scattering patterns are divided in 16 segments. The intensity at a predefined radius range, is integrated in each segment and plotted as a function of the segment angular position. The datapoints are aproximated by a cosine curve. Information as the abundance, orientation and degree of orientation of the nanostructures in this range can then be extracted.

RECIPROCAL SPACE IMAGING

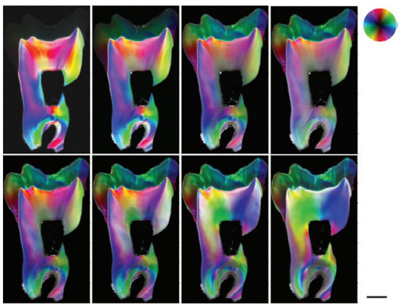


Scattering measurements, which belong to the reciprocal-space techniques, are characterized by an inverse relationship between the size of the inspected nanostructures and the scattering angle. Thus, by tuning the inspected angular range of the scattered X-rays, one can obtain insight in the morphology of the inspected specimen in the range below one micrometer down to the atomic structures. According to the angles of interest, scattering can be divided in small-angle X-ray scattering (SAXS), dealing with the ranges approximately between 2 and 200 nm, and wide-angle X-ray scattering (WAXS), which allows for the inspection of atomic species.



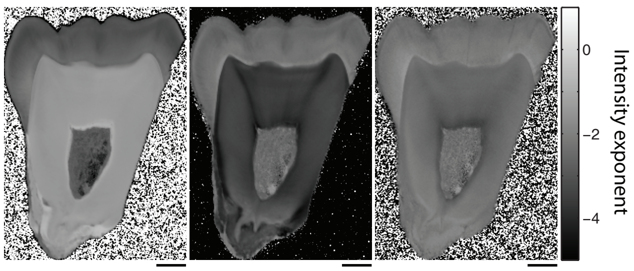
The scattering signal is closely related to the Fourier transform of the electron density distribution of the specimens. When different particles scatter simultaneously, the generated signal contains contributions from all of them, yielding a mean value from the illuminated volume.

DIRECTIONAL ANISOTROPIES



Processed scattering signal of a 400 µm thin tooth slice. The shown nano-structure ranges are 5 to 7 nm, 12 to 23 nm, 34 to 46 nm, 46 to 64 nm, 71 to 92 nm, 106 to 120 nm, 138 to 162 nm and 183 to 212 nm from top left to bottom right. The colors are according to the orientations of the scattering signal, see color wheel, their brightness relates to the nanostructure abundance.

SHAPE ANISOTROPIES



The slope of the scattered intensity as a function of the scattering vector q is closely related to the shape of the scattering nanoparticles. Spherical scatterers exhibit an intensity decay proportional to q^{-4}, while 2D disc-like structures present a decay proportional to q^{-2} and needle or rod-like structures proportional to q^{-1}.

The figure above shows this exponent for one tooth slice in the ranges corresponding to 20 to 30 nm, 50 to 60 nm and 90 to 100 nm.

Between 20 and 30 nm, the dentin appears to contain structures with no dimension significantly larger than the other, while in the enamel disc to rod-like scatterers can be found. In the range between 50 and 60 nm volumetric scatterers are found in the enamel while disk or rod-like structures are predominant in the dentine. When looking at structures around 100 nm, an uniform signal of volumetric scatterers is obtained for the whole specimen.

CONCLUSION AND ACKNOWLEDGEMENT

X-ray scattering in scanning mode is a powerful technique to uncover the nano and sub-nano-structure of human teeth over macroscopic areas. In human teeth, strong anisotropies are found along the whole nanometer range and below. The organization of tooth hard and soft tissues clearly relates to the mechanical properties. The insight gained on the morphology of organic and inorganic components should provide the means to further develop nanodentistry treatment possibilities, such as biomimetic fillings or remineralization procedures with nanoparticulate bioglasses.