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Nondestructive Visualization of Demineralization using µCT-Synchrotron Radiation

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Introduction

Because of an intact surface initially dematerialized enamel often remains clinically undetected. Conventional dental radiology only permits two dimensional imaging with limited resolution. Even by using light optical microscopy it is only possible to detect demineralized enamel which has already taken irreversible biological damage. The purpose of this work was to verify the applicability of µCT-synchrotron radiation for early diagnosis of demineralization in enamel under laboratory conditions. This method promises a nondestructive 3D-visualization of mineralized structures in micrometer-range with high resolution and allows quantification of the mineralization grade.

Material and Methods

Electrons that are accelerated to high speed by magnetic fields while circling on a closed loop emit electromagnetic radiation with a wavelength of 10^{-6} m to 10^{-11} m. This kind of emission is called synchrotron radiation.

Radiation characteristics:
• a nearly parallel, monochromatic beam provides ideal conditions for imaging methods by high resolution and high density contrast
• higher intensity, the flow of radiation and a wide energy spectrum allow better analysis of the object by the possibility of specific adaptation of the quality of radiation on the object's characteristics compared to X-ray radiation

In situ study:
Into four removable intraoral mandibular appliances we polymerized 32 autoclaved enamel samples of human third molars under a gold-micromesh (Fig. 4). The contact of the probes with the oral cavity was given and therefore undisturbed growth of plaque was ensured. The desired demineralization should originate from acid producing bacteria and the consume of acid and carbohydrate containing food in a natural way. In total we randomly chose four participants to wear an appliance, each with eight enamel samples for 29 days.

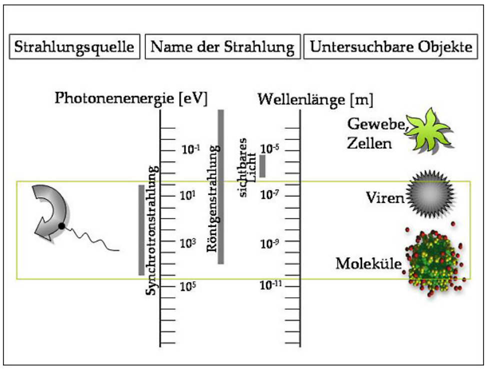
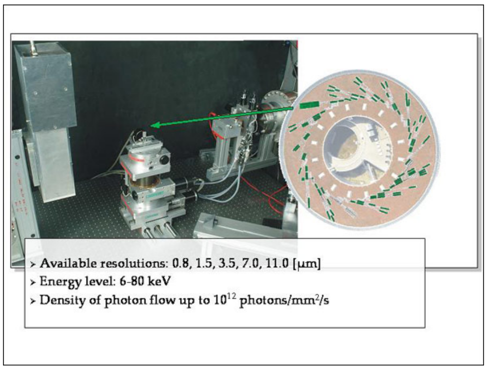


Fig. 1: Photon energy and wavelength spectrum

Fig. 2: Synchrotron BESSY II, Berlin, Germany



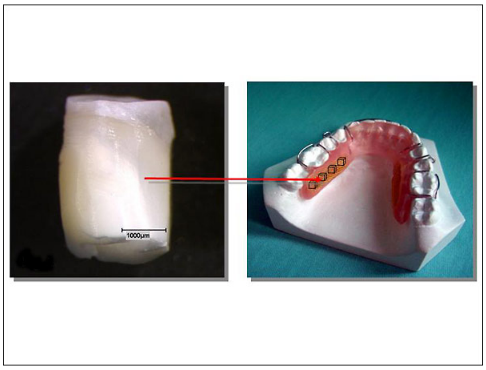
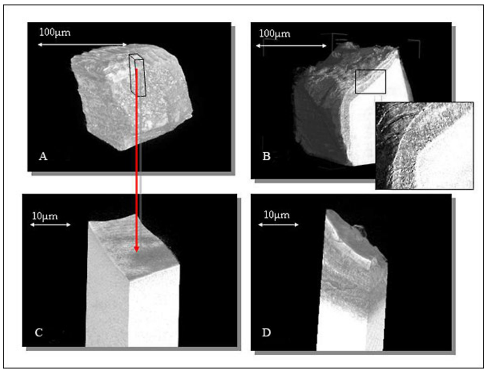


Fig. 3: Test bench for synchrotron tomography at the storage ring BESSY II in Berlin, Germany Tomography@BAMline (monochromatic hard X-ray)

Fig. 4: Autoclaved sample and mandibular appliance with golden micromesh

Results

Before and after the In situ Study 3D-pictures of the samples were generated. For further analysis we selected a block of 200^3 pixels from the total tomogram (Fig. 5 A, 5 B) and saved it as a picture (Fig. 5 C, 5 D).
Every picture line perpendicularly to the samples surface represents a density profile in this data file.
Tomographic sagittal cut of an enamel sample showing progression of demineralization. Unaltered enamel structure (a), early (b), advanced (c), irreversibly damaged enamel with manifested caries (d).

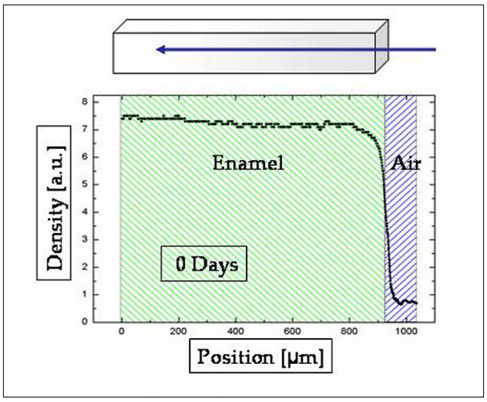


The density profile permits to draw conclusions on the mineral rate of the samples. The density calculation is based on **Lambert-Beer's Law of Absorption:**

$$I(x,y)=I_0 \exp(-\int \mu(x,y,z)\, dz)$$

$I(x,y)$: Intensity of transmitted ray
I_0: Intensity of incident ray
$\mu(x,y,z)$: Density dependent absorption factor

Fig. 5, 6: Before: The sample shows a regular enamel structure (A, C). After: Pictures of the sagittal cut (Fig. B) and the selected block (Fig. D) visualize structural change of enamel accentuated in grey. Both samples have an intact surface.



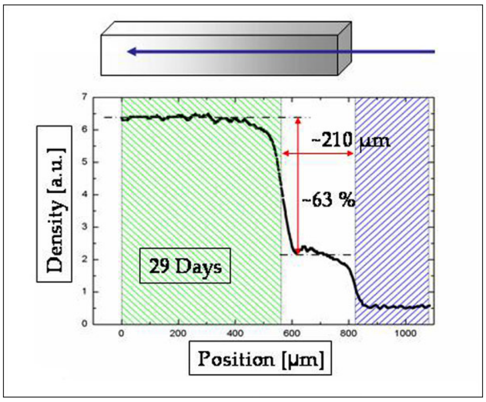


Fig. 7: Density profile, 0 days

Fig. 8: Density profile, 29 days

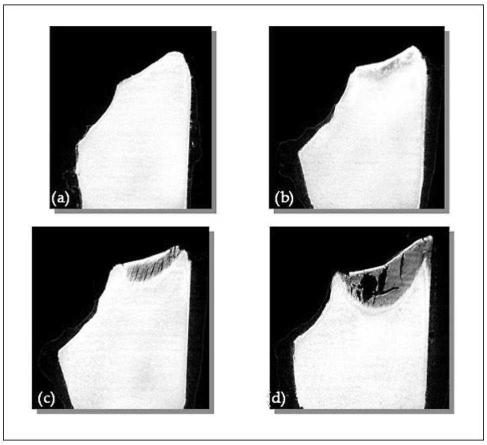


Fig. 9: Tomographic cut

Conclusions

µCT-synchrotron radiation is a noninvasive, nondestructive method with high resolution for three-dimensional visualization of minimal structural changes of enamel. A reduced degree of mineralization lowers the enamel density which results in a decreased absorption coefficient. The depth and grade of structural changes can be quantified over different time periods. Synchrotron imaging has great potential in combination with other methods like X-ray diffractometry for further analysis of internal micro-structures during de- and remineralization processes of enamel. Detailed analysis of remineralization cycles of enamel will be topic of future research.

This Poster was submitted by Julia Lautensack.

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