Optically stimulated luminescence (OSL) in tooth enamel for post-radiation exposure dosimetry

Specific goals

To investigate the possibilities for retrospective in vivo absorbed dose measurements using optically stimulated luminescence (OSL) in tooth enamel.

The project will be carried out in three steps of which steps 1 and 2 are included in this proposal:

1. To find optimal OSL detection conditions for hydroxyapatite (the main constituents of dental enamel).
2. To use the findings from (1) to optimize OSL measurements of crushed dental enamel and in intact enamel on extracted teeth.
3. To make measurements on tooth enamel in vivo.

Background

A wide range of authorities and expert groups stresses the importance of a measurement technique that can be used for radiation dose reconstruction for individuals after unplanned exposure to ionising radiation. Since it is particularly important to quickly identify those individuals that have received harmful levels of ionising radiation, such a technique needs to be rapid (take less than 5 minutes per measurement) and be able to estimate individual doses in the range of 1-10 Gy. That would allow for a fast triage, so that overexposed individuals could be given the proper medical treatment or be taken under special observation or isolation. In recent years, a large number of cytogenic assays have been developed mostly based on DNA and chromosomal damage in peripheral lymphocytes. The results of such sample tests are very important for the estimation of the consequences of the irradiation, but a big problem is that the results are normally not available until after two days, at the earliest, which in many cases is too long to wait. There is therefore a great need for additional technologies that can provide an immediate answer in terms of absorbed dose. Both electron paramagnetic resonance (EPR) and OSL has the potential to be used as rapid methods for individual retrospective dosimetry, as they use materials that accompanies the individual as personal accessories in clothing and pockets (pharmaceuticals, credit cards, chewing gums, sweets etc) or are frequently available in people’s homes (bricks, tiles, porcelain, salt, sugar, detergents, pharmaceuticals, etc).

The best indicator to reconstruct individual doses is if biological material from the exposed person is used. One attempt to do this is to use tooth enamel, which mainly consist of hydroxyapatite. It has been shown that hydroxyapatite have a measurable EPR-signal for absorbed doses over 0.1 Gy (see for example Güttler et al., 2007; Onori et al., 2008). It is however impossible to carry out in vivo measurements by using EPR since microwave radiation is generated in the presence of strong magnetic fields. Thus, up to now, the use of EPR has therefore been limited to extracted teeth measured in the laboratory, which of course is a serious disadvantage of the technique. Hence, it would be of great advantage if the measurements could be performed non-destructively in vivo. One potential benefit of OSL dosimetry of tooth enamel is that the signal can be obtained through the use of harmless visible light, which hence will permit in vivo measurements. The problems with some OSL-instrumentation in the oral cavity will be small compared to the need to extract teeth for EPR. Moreover the OSL measurements can be made much faster (seconds to minutes) than EPR measurements (20-40 minutes). This means that a large number of individuals could be tested very quickly. In addition, the OSL signal is easier to interpret than an EPR spectrum.

Optically stimulated luminescence (OSL) is a process in which a crystalline material, previously exposed to ionising radiation, during stimulation by light of an appropriate wavelength (usually between 300 and 1000 nm) emits luminescence light in proportion to the absorbed dose. OSL is thus analogous to the thermoluminescence (TL) process with the difference that the stimulation of
Luminescence is achieved optically instead of thermally. The wavelength of the stimulation light can be chosen to fit the material properties and the optical stimulation can be continuous, pulsed or ramped. In both TL and OSL, the wavelength of the emitted luminescence light is characteristic of the crystalline material. In TL the luminescence is emitted at certain temperatures and in OSL the maximum luminescence is emitted at a specific combination of temperature, light wavelength and power density of the stimulation light source. Hence, the OSL protocol must be optimised for each material. Once the protocol is optimised for tooth enamel, the use of optical fibre cables would allow enable in vivo measurements.

OSL-measurements on tooth enamel were first proposed by Godfrey-Smith and Pass (1997), who showed that crushed human tooth enamel yielded OSL dose response under both infrared (IR) and green light stimulation. However, the early experiments succeeded in detecting only very large absorbed doses, in excess of 120 Gy. Yukihara et al. (2007) were able to obtain minimum measurable doses (MMDs) of 4-6 G y using green stimulation light. In a more recent paper, Godfrey-Smith (2008) used blue stimulation light with 50 mW stimulation power, which improved the technique and gave significant OSL signals for absorbed doses down to 1.4 G y, which means an improvement of two orders of magnitude compared to their earlier data.

Work plan

Tooth enamel's primary mineral is hydroxyapatite, which is a crystalline calcium phosphate (Ca₁₀(PO₄)₆(OH)₂). The first step in the investigation will be to study chemically pure hydroxyapatite with respect to sensitivity, background, fading properties etc in the same way as we earlier have done with NaCl and table salt. In the next step we will investigate human teeth in a similar way – first as crushed enamel, then as intact enamel and whole teeth.

In the future (not within the present application), a portable OSL-equipment will be constructed for use for tooth enamel in vivo.

Methods and working strategy

1. Optimal reading conditions for hydroxyapatite

The dosimetric properties of chemically pure hydroxyapatite will be investigated in a similar way as NaCl have been investigated previously in our group (Bernhardsson et al., 2009; Christiansson et al., 2008a; Christiansson et al., 2008b; Christiansson et al., 2010a; Christiansson et al., 2010b). We will evaluate the optimal OSL reading conditions for hydroxyapatite with respect to temperature, type of stimulating light, its timing and power density. The signal stability or fading with time after irradiation will be determined as well as the absorbed dose – OSL signal relations. All measurements will be carried out using an OSL reader (Risø TL/OSL-DA-15; Risø National Laboratory) described by Bøtter-Jensen et al. (2000), and equipped with IR and blue LEDs as stimulation sources.

At the laboratory measurements, each sample will be irradiated with one or several known doses after the initial OSL measurements yielding an individual calibration curve for each sample.

2. When an optimised read-out protocol is established we will continue with samples of human molar teeth, which will be obtained from the Faculty of Odontology at Malmö University (Prof Kristina Lindh) and to a limited extent from research group members and their colleagues. Teeth will be separated from the roots and the enamel layer cut in 1 mm slices from the side and from the top of the crowns by means of a laboratory diamond saw cooled with chilled distilled water. All visible dentine will be removed and the samples cleaned in acetone. Some pieces of enamel will be measured directly, while others will be crushed in an agate mortar and pestle and sieved into grains of sizes of <100 μm, 100-200 μm, 200-300 μm, etc. The material will be exposed both to the OSL reader's internal ⁶⁰Sr/⁶⁰Y beta source (20 MBq; 54 mGy/min at the irradiation position) and at defined positions in a ⁶⁰Co beam with well known absorbed dose rates (1-100 mGy/min).
The grains and enamel fragments, respectively, will be placed in carefully cleaned steel cups before the optical stimulation. The same basic parameters as for hydroxyapatite will be varied and optimised. Above that, also sensitivity and dose-signal relations and their dependence of grain size (crushed enamel), fragment weight and surface area (fragments). For intact teeth, tooth to tooth variability will be studied as well as signal stability (also in recently extracted teeth).

3. Considerations in connection with future in vivo measurements
The ultimate goal of the subprojects is to gain knowledge to be able to design and construct an in vivo measuring equipment.

Temperature: In the oral cavity, the temperature is 35-37.

Optical contact: It is essential to get a good and stable optical contact between the optical fibre and the measured teeth.

Bleaching: Studies of the ability of the sun, ordinary light bulbs, energy saving bulbs, fluorescent lamps etc., to influence the signal. The various light wavelengths and intensities will be simulated by light emitting diodes (LEDs).

Calibration: Since an in vivo measurement will not allow additional radiation test exposures of the teeth (analogous to the regenerative irradiation exposures given to the samples in the read out protocols of the stationary OSL-reader) an average, “universal” dose-response curve has to be used. As dose response curves are supposed to vary considerably between different teeth, there is a need for an improved calibration procedure. It has been shown that UV and gamma radiation induce similar EPR signals in tooth enamel (Rudko et al., 2007). Therefore it could be meaningful to investigate whether an UV-induced OSL-signal is proportional to the beta/gamma radiation signal. If so, the individual sensitivity for OSL dosimetry of a tooth could be measured by illuminating with a UV lamp (DeWitt, 2010).

Fading: Although fading introduces an additional uncertainty in the dose assessments in e.g. a triage situation, it might also prove to be an advantage if it can be demonstrated that the signal from previous medical exposures has faded and that the signal measured is only from the most recent exposure.

Others: In a next step also man made ceramics (Bailiff et al., 2002) as well as tooth replacements such as fillings and crowns will be studied in the same way as described for tooth enamel.

Research group and infrastructure
The present project is a part of an ongoing program for retrospective dosimetry carried out by the Medical Radiation Physics group in Malmö, Lund University. Two PhD-students, Maria Christiansson and Christian Bernhardsson, entered the project in 2006, first as “scholarship students” and since then as full time PhD students. Christopher L Rääf, PhD and the main applicant Sören Mattsson, work as their supervisors and as senior researchers in the project. The group has access to the infrastructure of the Medical Physics Group in Malmö as well as to the Department of Radiation Physics at Skåne University Hospital Malmö. The group has a well-established cooperation with the Radiation Research Department at Risø National Laboratory/Technical University of Denmark and a close cooperation with radiation protection organizations in Sweden, Germany, Russia and Belarus.

Preliminary results
The principle of the measurements on crushed enamel samples is very similar to the work we have done on NaCl and table salt in our research group (Bernhardsson et al., 2009; Christiansson et al., 2008a; 2008b, 2010a; 2010b). Our research program has lead to improvements and full optimisation of NaCl as an emergency dosemeter over a wide dose range, from levels below 1 mGy up to tens of Gy.

For tooth enamel, Figure 1 shows preliminary results on the OSL signal after stimulation of a piece of tooth enamel with blue light 4 hours after irradiation with 9 Gy, 1 Gy and 0.5 Gy with the internal $^{90}$Sr/$^{90}$Y source. The minimum detectable absorbed dose is estimated to 65 mGy and the
minimum measurable dose to around 0.3 Gy, which is better than what has earlier been reported and similar to the MDD, which today is possible with EPR (Gütter et al., 2007). The fading also seems to be lower than earlier reported by e.g. DeWitt et al., (2010). Further fading tests, which are more extended over time are required. Given that the measurements are preliminary and the measuring technique is not yet optimized, the results are very encouraging.

Figure 1. OSL signal after blue light stimulation of a 44 mg fragment of tooth enamel, which has been irradiated with 9 Gy, 1 Gy and 0.5 Gy, respectively, 4 hours before read-out.

Significance

It is likely that it will be possible to non-invasively detect and quantify absorbed doses at sub-lethal doses, by measuring the OSL-signal from tooth enamel. Results up to now are encouraging for a future design of a portable in vivo OSL device for use in radiological or nuclear emergencies. It may also be of interest for dosimetry in connection with diagnostic radiology and radiation therapy in the head and neck region. In comparison with EPR dosimetry, OSL dosimetry can be used in vivo, requires much less complicated and costly equipment for signal read-out. It may potentially require much less invasive sampling. It has a rapid readout and repeated measurements can be done at various locations in the patient’s oral region. It may also be used for measurements on manmade ceramic tooth replacements.

Description of how results are communicated

All results will be discussed openly and presented at conferences, in conference proceedings and in papers published in the scientific literature.
References


Christiansson M, Mattsson S, Rääf C. A simplified OSL-algorithm for low dose retrospective dosimetry using household salt. Proc 3rd European IRPA Congress 2010, June 14-18, Helsinki, Finland 2010b


