Retrospective Dosimetry with Teeth: Way from State-Of-Art Laboratory Technique to Routine Tool

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Introduction

EPR dosimetry with teeth is generally accepted as a highly attractive methodology for reconstruction of individual doses long time after exposure. However till the recent time, practical implementations of this technique were essentially unique state-of-art pieces of laboratory technology incapable for practical dose reconstruction. Moreover, the accuracy and consistency of results produced by EPR dosimetry were not proven. The challenge of the present time is to bring this technique to the stage of routine tool which would incorporate both accuracy and high technological performance. On the way towards this goal, efforts in several directions should be undertaken. First, methodological research called to harmonize techniques developed worldwide and bring EPR-dosimetry to the degree of technological perfection. Second, quality a assurance program in order to ensure both consistency and accuracy of results. Third, investigation of fundamental aspects of EPR dosimetry with teeth aiming to resolve present shortcomings and discover new horizons in this area. Research activities presently performed in the Radiation Protection Institute (RPI) address all the mentioned above issues.

Development of optimal technique

During the last four years a semi-routine version of EPR technique was developed and implemented in Ukraine.

With respect to the demands of epidemiological follow-up, optimal EPR technique must meet following requirements:

- sensitivity of the technique and accuracy of the results must be adequate to practical needs of post-Chernobyl follow-up;
- results produced by the technique must be consistent with other (independent) dosimetric methods and internal standards;
- the technique must be reproducible and portable i.e. the results should be reproducable at different times and in other laboratories;
- performance of the technique must be high enough to meet practical demands.

With respect to the listed above criteria, each of the basic steps of EPR-dosimetric methodology was subjected to rigorous analysis and optimization. As may be seen from Fig.1, practically every step had incorporated a number of innovations and specific features making the technique a complete piece of technology. The technique allows for reconstruction of doses in excess of 100 mGy within 40% error interval. The technique itself have been explicitly presented [1,2] and is widely accepted worldwide.

A new, elaborate methodology of sample preparation is one of the most efficient innovations, introduced into the EPR-dosimetric technique. Application of this procedure leads to the substantial reduction of background EPR signals which normally are superimposed with radiation induced signal in tooth enamel making detection of doses below 0.5 Gy difficult. Since the properties of original material vary, the degree of the purification process needed to

obtain optimal specimen may be different. Accordingly, purification is normally performed in several progressive steps: failure of the given procedure leads to application of further treatment.

An effect of the sample purification is illustrated at Fig.2. The figure demonstrates EPR spectra of the same low dose sample recorded before and after application of the above procedure. It is clearly seen, that the spectrum was improved drastically making dose reconstruction with this sample possible.

Although capabilities and performance of RPI version of EPR technique were proven, further development and harmonization with other existing techniques is needed. Such harmonization of EPR techniques used in different laboratories and development of the standard technique is aimed in the Framework IV EU-Dose Reconstruction Program. This task will include series of tests covering sample preparation procedures and EPR spectra processing. Basing on the results of this three year effort, recommendations concerning implementation of EPR for retrospective dosimetry with teeth will be given to facilitate utility of EPR dosimetry in wider scale.

Quality assurance

Since reconstruction of individual doses is usually endowed with high responsibility, special attention in the development of EPR technique should be paid to guarantee reliability of the results. In order to check consistency and accuracy of the results produced by the technique, special quality assurance program was designed and implemented.

This program had included a series of internal tests (including spectrometric standardization and check of laboratory irradiator) and cross-calibrations with other laboratories worldwide.

In this series, the most comprehensive cross-calibration was performed in collaboration with the Center of Applied Dosimetry, University of Utah, USA (E.Haskell, R.Hayes)*. The cross-calibration was performed in several stages, namely:

- intercalibration using samples of tooth enamel with uniform properties which were exposed under laboratory conditions;
- intercalibration using whole teeth exposed *in vitro*;
- intercomparison using liquidator's teeth accidentally exposed *in vivo*.

Every next stage more closely approximate the reality. So, if the first stage was dealing with rather ideal samples, the third intercomparison had involved a full-scale dose reconstruction using teeth specifically from exposed individuals. However, the interpretation of the results of the advanced tests became more difficult due to an increasing number of uncertain factors affecting the final result of dose reconstruction.

The results obtained in course of the cross-calibration with the US laboratory, in general, brought confidence in adequacy of the dose assessments by EPR dosimetry with teeth.

At the first stage, the simplest intercalibration was performed with non-realistic but extremely uniform samples. The advantage of the intercomparison design was the possibility to objectively judge the results; there were no uncertain factors which could lead to a fuzzy interpretation of the dose determinations. As may be seen from the Fig.2, the results obtained in RPI had demonstrated an excellent agreement with the preset dose values [3].

As expected, the results of the second stage intercalibration were not so clear-cut and their interpretation could not be performed in definitive way. Both laboratories had demonstrated good (within 17%) agreement

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with nominal dose values, although the results produced by the RPI technique tended to overestimate the doses to teeth. The latter may be explained by the contribution of the life-time dose (particularly medical X-ray exposure) into the total dose to tooth which, actually, was determined as a result of dose reconstruction. Since the detected doses corresponding to the pre-intercalibration history of the teeth were found to be below the threshold of reliable dose reconstruction, the correction of the results was, unfortunately, impossible.

The third stage of cross-calibration - dosimetry with real teeth from liquidators exposed in vivo - had demonstrated worse results. The doses, determined in different laboratories had coincided within declared uncertainty ranges only for 2 individuals of 5. Some of the samples had demonstrated significant (up to 60%) deviation of results obtained in the two laboratories. The results of this intercomparison are presented in [4]. At the present stage of the intercomparison it is impossible to determine the major reasons for these discrepancies. Adequate interpretation of the results requires additional investigations and, possibly, conduction of the intercomparison with partially modified design. One of the possibilities could be to use for intercomparison teeth from individuals with doses, assessed by independent methods of retrospective dosimetry (such as FISH test or analytical dose reconstruction).

Investigation of fundamental aspects of EPR dosimetry

Although performance and abilities of the technique were tested in series of cross-calibrations and routine dose reconstruction, there are several issues of key importance which need to be resolved before the extensive use of EPR dosimetry with teeth for dosimetric support of follow-up studies. These yet unresolved problems may cause a threat to the utility of EPR dosimetry. Some of these effects are known for a long time, some other were discovered recently. Among those are the well known effect of enhanced sensitivity to low-energy photons and the recently reported generation of paramagnetic centers by UV light [5]. An effect of non-linearity of dose-response curves in the dose range below 1 Gy was observed by the authors only during the routine dose reconstruction and is yet unpublished.

Irradiation of tooth enamel with low-energy photons may lead to substantial (up to seven times) overestimation of tissue absorbed dose. This effect has a pronounced energy dependence with the highest oversensitivity at 60 keV. The signals from paramagnetic centers produced by high energy (accidental) and low energy (medical X-ray) photons are identical, making discrimination of these signals by means of EPR impossible. As a result, a dose measured by EPR is a sum of an accidental component (dose of interest) and a value caused by medical exposure. The degree of significance of the latter depends on the relative value which is a function of incidence energy, dose per examination and the number of examinations. This means that the type of X-ray apparatus used in the dental practice is very important, determining, after all, the degree of significance of X-ray component. In order to clarify this issue it is necessary to conduct a systematic investigation of effects connected with X-ray exposure. This investigation should include both experimental and theoretical evaluation of dose responses prompted by different types of X-ray examination including different geometry, X-ray apparatus and dose per examination. The problem of doses deposited to neighboring and opposite teeth should be studied too. Contribution to the tooth dose of different types of X-ray examination (e.g. gamma-tomography, panoramic diagnostics of scull, etc.) and radiotherapy is still unknown and

requires special investigation. This work will demand a use of both mathematical and physical phantoms for simulation of realistic situations.

The result of this work should be either a conclusion about insignificance of X-ray contribution to the tooth dose (and establishment of the application limits for this assumption) or recommendations how to mitigate or account an effect of X-ray examination.

Another phenomenon which may affect the reliability of dose reconstruction with tooth enamel is the generation of paramagnetic centers by UV light. The information about the role, qualitative and quantitative characteristics of this effect is quite contradictory. Initially this effect was discovered and reported by Ivannikov et al. in 1995 [5]. The series of experiments conducted worldwide to study this effect brought no clarification about this question. It is expected that an effect of UV irradiation is most pronounced for front teeth, such factors as time spend outdoors, elevation of the living area over the see level etc. may also influence the degree of this effect. At present time the problem of UV-irradiation needs to be approached in systematic way; this phenomenon must be studied from the point of view of physical, spectrometric and kinetic properties. Processes of generation of paramagnetic centers as a function of wavelength and intensity of UV light and decay of these centers should be investigated in order to obtain clear view of this effect. The study of spectrometric properties (e.g. saturation of the signals) may yield an approach to discrimination of UV and radiation induced signals by means of EPR technique. The investigation of depth profiles of UV-generated signals in tooth for different energies of UV photons and daylight UV spectrum will give a knowledge about the attenuation of UV light in enamel and could be used for target etching of exposed fractions of tooth enamel. Recommendations concerning account and mitigation of this effects should be issued as a final point of this research.

Non-linearity of dose response curves in the dose range below 1 Gy was observed at some teeth in course of routine dose reconstruction for liquidators. Formerly, saturation of the dose-response curve was observed only at doses above ten Gy, below this range, the curve was considered to be linear and this property is widely used for extrapolation of calibration curves to the low-dose regions. Moreover, the techniques based on the use of a single calibration factor (without additive dose) critically depend on the linearity of the dose-response function. Non-linearity of dose response curves may have significant influence on the results of dose reconstruction. Neglecting of the non-linearity of calibration curves leads to substantial under- or over-estimation of individual doses. Advanced study of this effect, investigation of factors having impact on the dose-response curve, development of methods of extrapolation of additive-dose curves are needed in order to solve the problem of accurate and reliable retrospective dosimetry using teeth as natural dosimeter. Since this effect takes place only in about 5% of cases, the scope of dose reconstruction should be large enough to provide consistent and statistically significant conclusions.

Conclusions

As a result of extensive research, EPR dosimetry with teeth was brought to the level of semi-routine technique for evaluation of doses received by individuals highly exposed after the Chernobyl accident.

Special attention was paid to quality assurance of this high-tech methodology in order to provide accurate and reliable individual dose assessments. The quality assurance program had included several International cross-calibrations using a variety of specimens from pulverized tooth enamel

at initial stage to whole teeth from liquidators exposed in-vivo at the final phase of intercomparison.

However, the recent research and developments in the field of EPR dosimetry made obvious a need for further investigations. From the pragmatic point of view, these investigations should be conducted along the following directions:

- investigation and development of approaches to the account of EPR signals induced by the life time medical X-ray exposure;
- comprehensive study of effects in tooth enamel caused by UV light;
- investigation of the factors causing non-linearity of the dose response function in the dose range below 1 Gy and development of approaches to the account of this effect in dose determination;
- cross-validation of EPR dosimetry with independent methods of retrospective dosimetry; this may be achieved by parallel application of different methods (e.g. EPR, FISH and analytical) to the same objects;
- methodological research aiming improvement of the technological capabilities of EPR dosimetry and enhancement of the productivity of the technique.

Completion and success of the outlined efforts will turn EPR dosimetry from a quite exotic methodology to an ordinary dosimetric routine like gamma-spectroscopy, alpha-counting etc. International collaboration and labor sharing in this area has demonstrated its extreme utility; joint efforts in filed of EPR-dosimetry would bring the technique to the qualitatively new stage approaching the solicited level of routine procedure for dose reconstruction.

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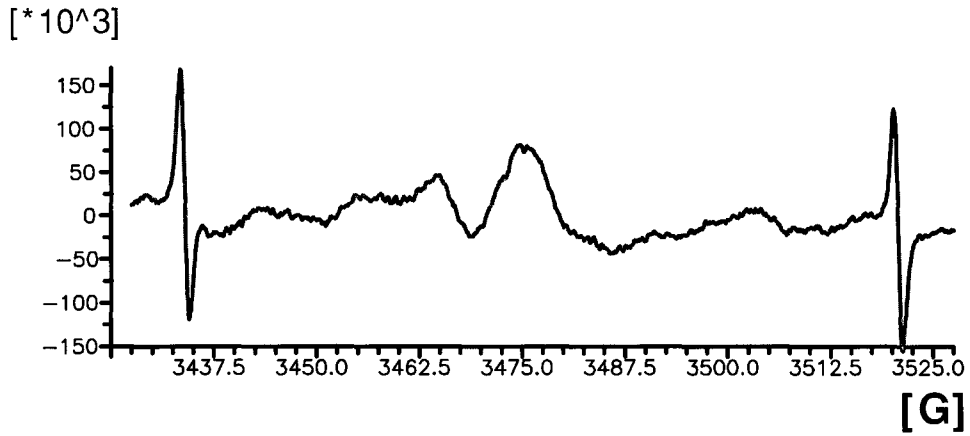
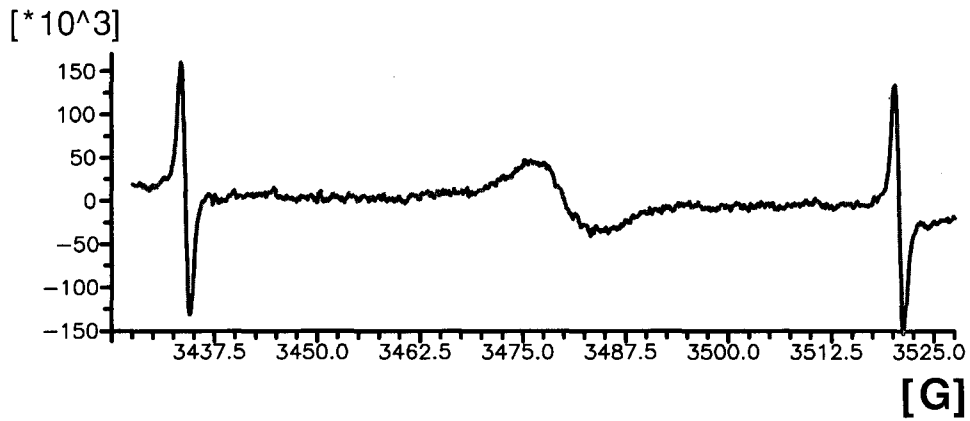


(a)



(b)

Fig. 1. Effect of sample purification.

EPR spectra prior (a) and after (b) purification of the low-dose sample.

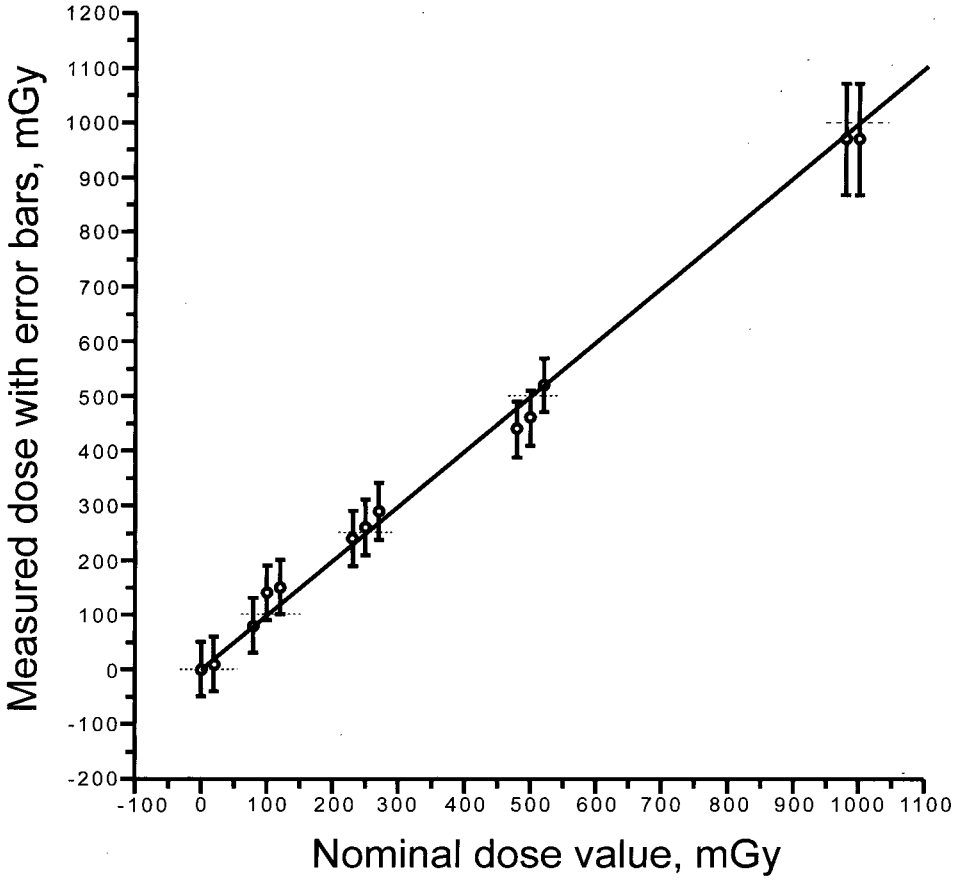


Fig.2. SCRM results of intercalibration with homogenized samples. Measured doses vs. nominal dose values.