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Applied Radiation and Isotopes 62 (2005) 293–299
Applied Radiation and Isotopes
www.elsevier.com/locate/apradiso

Measurements of clinically significant doses of ionizing radiation using non-invasive in vivo EPR spectroscopy of teeth in situ

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Abstract

There are plausible circumstances in which populations potentially have been exposed to doses of ionizing radiation that could cause direct clinical effects within days or weeks, but there is no clear knowledge as to the magnitude of the exposure to individuals. In vivo EPR is a method, perhaps the only such method that can differentiate among doses sufficiently to classify individuals into categories for treatment with sufficient accuracy to facilitate decisions on medical treatment. Individuals with significant risk then can have appropriate procedures initiated immediately, while those without a significant probability of acute effects could be reassured and removed from the need for further medical treatment. In its current state, the in vivo EPR dosimeter can provide estimates of absorbed dose of ± 25 cGy in the range of 100–>1000 cGy. This is expected to improve, with improvements in the resonator, the algorithm for calculating dose, and the uniformity of the magnetic field. In its current state of development, it probably is sufficient for most applications related to terrorism or nuclear warfare, for decision-making for action for individuals in regard to acute effects from exposure to ionizing radiation.

Keywords: In vivo; Retrospective dosimetry; EPR; Teeth; Radiation accidents; Terrorism; After-the-fact dosimetry

1. Introduction

There are plausible circumstances in which populations potentially have been exposed to doses of ionizing radiation that could cause direct clinical effects within days or weeks, but there is no clear knowledge as to the magnitude of the exposure to individuals. It is likely that many of the individuals will not have received clinically significant doses of radiation, while others may have been exposed to potentially life-threatening doses. A method that could differentiate among doses sufficiently to classify individuals into categories for treatment with sufficient accuracy to facilitate decisions on medical treatment could have great benefit. Individuals with significant risk could then have appropriate procedures initiated immediately, while those without a significant

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0969-8043/$ - see front matter
doi:10.1016/j.apradiso.2004.08.016

probability of acute effects could be reassured and removed from the need for further medical treatment. Such a division into appropriate treatment classes could be extremely valuable under circumstances such as a terrorist incident or accidental release of radiation (e.g. the Three Mile Island incident), in which many people feel that they may have been exposed. The immediate measurements at the individual level would minimize panic and allow limited resources to be used most effectively. Until recently, methods to make such measurements have not been available.

Potentially this might be done biologically by measuring a direct biological effect that is proportional to the dose of radiation. This is very difficult to accomplish, however, because the amount of energy that is deposited in an exposure even to lethal doses of radiation is extremely small. Therefore, there have been attempts to use subsequent biological changes, such as radiation induced chromosomal changes. As noted in the ICRU report #68, however, the biological dosimetric methods (which include methods based on assays of chromosomal aberrations, micronuclei, or mutations) at the present state of development are not able to provide individual dose assessment, primarily because of problems with the calibration for the methods. Perhaps most importantly for the purpose, these methods also require time to evolve and also require removal of samples for sophisticated processing to obtain even qualitative data, and these characteristics are suboptimal for the purpose of dealing promptly with potential exposures.

Potentially there would be significant advantages in the use physical phenomena to measure the radiation dose in individuals, which would not require the evolution or processing needed for the biologically based methods and which would be more readily calibrated. There do not appear to be any such possibilities, however, with one notable exception—the induction of long lived radiation-induced paramagnetic species. Ionizing radiation creates unpaired electron species as a direct result of its interactions with molecules. While most of these react immediately and disappear, some will be stabilized for long periods of time if they are generated in an appropriate matrix. The hydroxyapatite component of bone and teeth is such a matrix. This phenomenon has been exploited to make measurements on isolated teeth, but not in vivo.

We report here such a method, based on in vivo electron paramagnetic resonance (EPR or ESR) of teeth, which appears fully to meet the requirements for after-the-fact dosimetry applicable to individuals. It appears to meet fully the desirable characteristics of a method that provides an adequate solution to the problem including:

1. Sufficient sensitivity to measure clinically relevant doses.
2. Provides unambiguous data that is sufficient to make the differentiation into the designated dose sub-classes.
3. Applicable to individuals.
4. Non-invasive.
5. Provides the data rapidly and clearly.
6. Can operate in a variety of environments.
7. Can be operated by minimally trained individuals.

One of the important considerations for developing a useful system is to recognize what is required to meet the real needs for this type of retrospective dosimetry. It is to be able to measure the dose rapidly and with sufficient accuracy to discriminate among exposures sufficiently to allow for the accurate placement of individuals into appropriate channels for further action. The categories that are needed to be differentiated are:

- Exposures that are very unlikely to cause any acute symptoms (<50 cGy).
- Exposures that are likely to lead to mild and delayed clinical symptomatology (75–150 cGy).
- Exposures that are likely to lead to moderate to severe clinical symptomatology (150–300 cGy).
- Exposures that are likely to lead to early severe clinical symptomatology with a potential for lethal outcome (>300 cGy).
- Exposures that are very likely to lead to early death (>600 cGy).

It is important to recognize that methods and procedures that provide less accuracy than about ± 50 cGy would be suboptimal but probably still useful, even with uncertainties as high as ± 100 cGy. And improvement of the resolution of doses to less than ± 25 cGy would probably add little if any value for the purpose of placing subjects into appropriate categories for action. This is because the intrinsic variation in the response of individuals to ionizing radiation is sufficiently large that very precise information on the doses could not usefully improve the categorization of the subjects into action classes.

The ability of EPR retrospectively to measure the dose of ionizing radiation was established more than 35 years ago (Brady et al., 1968). It is based on the fact that the radicals created by ionizing radiation can be stabilized within the matrix of bone and teeth. This phenomenon has been recognized in bone and teeth for more than 50 years (Gordy et al., 1955; Swartz, 1965; Swartz et al., 1965). Subsequently, this technique has been used productively on isolated teeth and bones to measure radiation doses from radiation accidents and heavy environmental radiation contamination. Using this approach, it has been possible to measure doses in the range of cGy in isolated teeth. Teeth are especially attractive because the signal intensity is stronger in them