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Complex experimental research on internal tooth dosimetry for the Techa River region: A model for ^{90}Sr accumulation in human teeth formed by time of intakes

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Abstract

Samples of calcified tooth tissues (enamel, root and crown dentine) collected from the Techa riverside population exposed to radiation caused by radioactive releases from the nuclear weapon plant in South Ural were investigated. Accumulated absorbed dose in the samples was measured using the EPR-spectroscopy method. Beta activity of the samples containing radioactive ^{90}Sr was measured by the method of low background anti-coincidence thin scintillating detection. High correlation between absorbed dose and beta activity was observed for enamel and root dentin but not for crown dentin. Otherwise, poor correlation was observed between absorbed doses as well as between beta activities for different tooth tissues of the same tooth. The results of dose measurement by EPR spectroscopy are analysed with the use of Monte Carlo simulation of dose formation due to ^{90}Sr incorporated in tooth tissues taking into account biological elimination of ^{90}Sr. Influence of ^{90}Sr distribution in the tooth body on absorbed dose is discussed.

Keywords: Internal dosimetry; External dosimetry; EPR/ESR; Tooth enamel

1. Introduction

Vast territories of South Ural region were contaminated as a result of radioactive wastes released by the Mayak Production Association into the Techa River in 1949–1956. During this period 76×10^6 m^3 of liquid wastes with total activity of about 10^{17} Bq were discharged into the river. The radioecological conditions and dosimetric investigations in this region are described elsewhere (Marey, 1959; Stepanenko et al., 1990; Degteva et al., 1994; Vorobiova et al., 1999; Tolstykh et al., 2003).

About 98% of total activity was released in the period from March 1950 to October 1951. The average daily release during this period was 1.6×10^{14} Bq with the following contribution of different radionuclides to the total activity: ^{89}Sr—8.8%, ^{90}Sr—11.6%, ^{137}Cs—12.2%, ^{95}Zr–^{95}Nb—13.6%, ^{103,106}Ru—25.9%, and rare-earth elements—26.8% (Vorobiova et al., 1999). Exposure of the population (about 30,000 persons in the Techa riverside) was caused mainly by long-lived isotopes of ^{90}Sr (half-life 29 years) and ^{137}Cs (half-life 30 years). Internal irradiation was resulted primarily from bone seeking beta-emitting ^{90}Sr. External irradiation was caused primarily by ^{137}Cs (Degteva et al., 1994). External doses estimated using the Techa River Dosimetry System 2000 (TRDS-2000) (Degteva et al., 2000) expected to vary in the range from 0 to 3 Gy depending on residence history of individuals. The maximal doses of external exposure were estimated for residents of the Upper Techa region who lived in immediate proximity to the shoreline.

Estimated external doses could be validated by the method of EPR dosimetry. This method gives possibility to determine a dose accumulated in calcified tooth tissues (IAEA Report, 2002). For the population of the Techa riverside, a dose

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accumulated in tooth tissues is a result of both external and internal exposure. Therefore, in order to obtain external dose from EPR dosimetry data, the total accumulated dose detected by EPR should be corrected on internal dose contribution taking into account the presence of ^{90}Sr in the tooth tissues.

Several pilot studies of the teeth collected from population of the Techa riverside were aimed to find out the relationship between ^{90}Sr content in calcified tissues and cumulative dose (Tolstykh et al., 2000; Romanyukha et al., 1996, 2001; Wieser et al., 1996; Göksu et al., 2002). All these studies demonstrate significant influence of ^{90}Sr on cumulative dose in enamel that cannot be ignored in the framework of the Techa River dosimetry. In Tolstykh et al. (2000) internal dose formation was investigated for enamel of teeth that crown formation had been completed by the time of radioactive release in assumptions that the amount of ^{90}Sr incorporated in the enamel is negligible and the main source of internal dose should be the crown dentin; ^{90}Sr was assumed to be uniformly distributed in the whole dentin body (root and crown dentine). For Metlino residents (Upper Techa) the results of individual measurements using EPR were found to be consistent with the doses calculated according to TRDS-2000 approach (Degteva et al., 2005). In Göksu et al. (2002) accumulated dose in tooth tissues was compared with ^{90}Sr content in the same tissues. High correlation was observed for absorbed dose in enamel, root and crown dentin with beta dose rate from incorporated ^{90}Sr. No correlation was observed for beta dose rate in enamel and dentine as well as between absorbed dose in these tissues of the same tooth. For the population of the Techa region it was found that maximal doses in tooth tissues measured by EPR are observed for tissues, whose period of formation coincided with maximal releases of radioactivity (Romanyukha et al., 2000; Romanyukha et al., 2001; Tolstykh et al., 2003). The process of dose formation in dentine and enamel was analysed for dog's teeth after a short period of 52 h after injection of ^{90}Sr (Ignatiev et al., 1999; Shishkina et al., 2001). Good agreement was found for doses modelled using Monte Carlo method and experimental doses measured by EPR spectroscopy.

The objectives of the present work are the following: to investigate ^{90}Sr distribution and absorbed dose after 50 years of intakes in various calcified tooth tissues which were in the process of maturation by the time of radioactive releases into the Techa River; to analyse the effect of ^{90}Sr incorporated in tooth tissues on the absorbed dose determined by EPR spectroscopy. Teeth obtained from the residents of the Middle and Low Techa regions were used for this study.

2. Materials and methods

2.1. Sample collection and preparation

Teeth obtained from the Techa riverside donors were selected specifically for this study. Teeth were extracted according to medical indications in the frame of creation of URCRM tooth sample bank. Part of samples was collected from control uncontaminated localities of the South Ural region. Totally, 8 teeth of exposed people (22 samples of tooth tissues) and 2 teeth from controls (6 samples of tooth tissues) were studied. For these teeth the calcified tissues were at different formation stages at the time of radioactive releases (1950–1951).

Crown dentin and enamel samples were prepared by sawing off the surface enamel layer of the tooth by a diamond disk saw. Root dentin was prepared from the root sawed off from the crown. Dental cement was removed from the root by dental drills. In order to eliminate effects of mechanically induced radicals due to mechanical treatment, the sawing was performed at low linear speed under water-cooling. Dentine and enamel fragments were crashed by nippers to chips of 0.5–2.0 mm in size. After mechanical treatment, the samples were etched 2–3 min in 20% acetic acid at room temperature, then rinsed up by distilled water, ethanol and dried.

2.2. EPR dosimetry

2.2.1. EPR spectra measurement and spectra processing

EPR spectra measurement was performed at room temperature with the use of ESP-300E (Bruker, Germany) X-band spectrometer equipped with high sensitivity TM_{110} mode cavity ER-4108-TMH. The following registration parameters were taken: microwave power 10 mW, modulation 0.3 mT at 100 kHz, sweep width 8 mT, sweep time 165 s, receiver time constant 163 ms, number of accumulations 16. Fourth line of an Mn^{2+} containing sample permanently mounted near the bottom of the cavity was used as a reference amplitude signal. Aliquots of 100–130 mg sample mass were used for measurements.

Spectra processing was performed with the use of the basic software of the built-in spectrometer computer as described in Skvortzov et al. (1995). A dosimetric radiation-induced signal was obtained by subtraction of a simulated native signal, which was obtained from a standard spectrum recorded for enamel of milky teeth. Shift, amplitude and width of the standard spectrum were changed using control knobs of the computer to fit a low-field part of the recorded spectrum where the native signal is positioned. The same standard spectrum was used for simulation of the native signal both in enamel and dentin. The intensity of dosimetric signal was determined as amplitude of its maximum. This methodical approach was tested at 2nd International Intercomparison on EPR tooth dosimetry (Wieser et al., 2000), and an accuracy of dose determination in enamel was characterized by mean standard deviation of experimental doses from nominal doses as 32 mGy in dose range up to 800 mGy.

2.2.2. Sample irradiation

Irradiation of dentin and enamel samples was performed by ^{60}Co gamma-ray source. Samples at irradiation were placed between two 4-mm polymethylmethacrylate plates. At such conditions of irradiation, dose absorbed in enamel and dentin is very close to dose absorbed in soft biological tissue (Wieser et al., 2000; Ivannikov et al., 2004). Therefore, dose values obtained with the use of tissue equivalent dosimeter (with standard uncertainty of 3%) were interpreted as doses absorbed in the samples.