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Radiobiological long-term accumulation of environmental alpha radioactivity in extracted human teeth and animal bones in Malaysia

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ABSTRACT

In this study, the radiobiological analysis of natural alpha emitters in extracted human teeth and animal bones from Malaysia was estimated. The microdistributions of alpha particles in tooth and bone samples were measured using CR-39 alpha-particle track detectors. The lowest and highest alpha emission rates in teeth in the Kedah and Perak states were 0.0080 ± 0.0005 mBq cm^{-2} and 0.061 ± 0.008 mBq cm^{-2}, whereas those of bones in the Perlis and Kedah states were 0.0140 ± 0.0001 mBq cm^{-2} and 0.7700 ± 0.0282 mBq cm^{-2}, respectively. The average alpha emission rate in male teeth was 0.0209 ± 0.0008 mBq cm^{-2}, whereas that of female teeth was 0.0199 ± 0.0010 mBq cm^{-2}. The alpha emission rate in teeth is higher in smokers (0.0228 ± 0.0008 mBq cm^{-2}) than in non-smokers (0.0179 ± 0.0008 mBq cm^{-2}). Such difference was found statistically significant ($p < 0.01$).

1. Introduction

Teeth are an extension of the skeleton and accumulate contaminating stable and radioactive bone-seeking metals that enter the human body. Hydroxyapatite (OHAp) and $Ca_{10}(PO_4)_6(OH)_2$ are used as models for the inorganic components of bones and teeth. Teeth are composed of several tissues, namely, dentine, enamel, cementum, and pulp. The main core of each tooth is composed of dentine and a highly sensitive calcified tissue. Dentine is covered with enamel at the crown portion and cementum at the roots. The alpha particle levels in teeth are 10 to 15 times greater than elsewhere in the body, and the distribution of activity shows considerable structure. Studies on autopsy tissues have mainly aimed at determining the levels for the principal alpha emitters present, namely ^{210}Po, ^{226}Ra, and ^{238}U. These nuclei are found in human tissues with typical activity values of 1 mBq g^{-1} to 3 mBq g^{-1}, 0.2 mBq g^{-1} to 0.3 mBq g^{-1}, and 0.05 mBq g^{-1}, respectively. Considering ^{210}Po occurs at the end of the ^{222}Rn decay chain, ^{222}Rn exposure is considered another potential source of increased ^{210}Po and ^{210}Pb in teeth.

Clemente et al. (1982, 1984) found a relationship between the ^{210}Pb content in teeth and the exposure to radon and radon daughters and determined that the incremental ^{210}Pb teeth content is due to excessive exposure to radon daughters, especially in people living near the BadGastein Spa in Austria. Henshaw et al. (1994) studied the uptake and microdistribution of the natural alpha radioactivity in human teeth using a CR-39 detector and found the transference of ^{226}Ra in the pulp and dentine teeth through systemic blood circulation. Yamamoto et al. (1994) measured the activity of ^{226}Ra in the human teeth and bones of the inhabitants at several locations in Japan. They reported the mean ^{226}Ra activity values of 0.23 and 0.41 mBq g^{-1} in the teeth and bones, respectively. The mean ^{226}Ra concentration (0.51 mBq g^{-1}) in teeth samples obtained from Tokyo is less than the concentration (1.11 mBq g^{-1}) reported for vertebral bone samples in this city. The radionuclide concentrations in teeth and bones are good indicators of the levels of radioactive contamination in the human body. Teeth have been widely used as markers of biological exposure to environmental pollution (Budd et al., 1998; Appleton et al., 2000; Carvalho et al., 2000; Gomes et al., 2004; Almayahi et al., 2014). CR-39 detectors are used in radon detection and alpha-particle spectroscopy to measure the natural alpha radioactivity in human and animal tissues (Henshaw, 1989, 1994; Almayahi et al., 2011, 2012a,b,c). ^{226}Ra and ^{228}Ra isotopes are considered the most important natural radionuclides of the ^{238}U

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and ^{232}Th series, respectively. The distributions for ^{238}U and ^{230}Th in bones are similar and have rather lower concentrations than ^{232}Th. These radioisotopes chemically and physiologically behave like calcium and tend to be concentrated in the bones and teeth (Dewit et al., 2001).

^{226}Ra is a well-known "bone-seeking" radionuclide that accumulates in calcareous tissues because of its chemical similarity to calcium (Whicker and Schultz, 1982). ^{226}Ra is expected to be present in bone tissues because this radionuclide tends to be moderately transferable in the physical environment. ^{226}Ra is taken up by vegetation from the soil, and assimilated efficiently from the gut when ingested by animals (NCRP, 1999). The retention of ^{226}Ra in bones is high and accumulates over time under conditions of chronic intake. The levels measured in human bones from several urban locations have ranged from 0.03 Bq kg^{-1} to 0.37 Bq kg^{-1} (Eisenbud and Gesell, 1997). Internal radiation dose varies with radionuclide concentration in air, soil, water, foodstuff, and rate of intake. This concentration differs from one human group to another. Therefore, radionuclides accumulated in teeth depend on the transfer rate of radionuclides from air, soil, and water to the teeth. ^{226}Ra uptake from public water supplies into teeth was studied as part of an evaluation of a radiological health problem (Samuels, 1964). The results of the study focused on radium metabolism as it relates to teeth (Samuels, 1966). Aghamiri et al. (2006) showed that the teeth of the inhabitants of Iran have more ^{226}Ra radioactivity concentration than those of the inhabitants of low-radiation areas because of higher ^{226}Ra content in soil and water. The present study assesses the uptake of natural alpha radioactivity in teeth and bones, determines how measured levels can be used as a marker of exposure to natural alpha radioactivity.

1.1. Study area

The total land area of Malaysia is 329,847 km^2. This country has two distinct parts, namely, Peninsular Malaysia to the west and East Malaysia to the east. Peninsular Malaysia (132,090 km^2) is located south of Thailand, north of Singapore, and east of the Indonesian Island of Sumatra. East Malaysia is located on the Island of Borneo and shares borders with Brunei and Indonesia. Peninsular Malaysia is situated between the latitudes 0 °N and 7 °N and longitudes 100 °E and 105 °E within the equatorial region of Southeast Asia and the maritime continent. The study was conducted in the Malaysian states of Penang, Kedah, Perlis, and Perak. The geographic locations of the sampling sites in West Malaysia are presented in Fig. 1.

2. Methods and materials

The alpha emission rate in individual teeth was determined using an α-sensitive plastic track detector (PADC-TASTRACK CR-39, Track Analysis Systems Ltd, Bristol, UK). All teeth used for the study were permanent teeth. The teeth were collected by dentists who also recorded information on each tooth, such as the age, gender, town, and smoking status of the donor (Table 1). Ninety-eight extracted human teeth samples were collected from fourteen clinics and hospital distributed across the four Malaysian states (Fig. 1). All tooth samples were sealed in vials and sterilized in formaldehyde (10% solution). The tooth samples were cleaned of soft tissue and organic material, washed with distilled water, and dried at a temperature of 70 °C for 3 h using an electric furnace. Only teeth without fillings were used in this study. Fifty-one animal bones (cow, fish, chicken, and mice bones) were collected from selected areas in the seventeen sites in West Malaysia (Table 1). The bone samples were collected from markets,

Fig. 1. A geographical map of West Malaysia and dental clinics sites.

except the bones of four mice collected from the areas around Penang. The bones samples were bagged and labeled with the name site and sample type. All samples were kept in an icebox after sterilization in formaldehyde (10% solution). The bone samples were deep-frozen to eliminate unwanted effects, such as tissue decay. The soft tissue surrounding the bones was removed from all samples. The bones were then incinerated at a temperature of 400 °C for 1 day in an electric furnace. The bones were homogenized by mortar and sifted through a 0.5 mm sieve. A hydraulic palletizing press (HERZOG Compression, Japan) was used to produce tablets 1.5 cm in diameter. All bone samples were pressed using a 30-ton piston.

The teeth selected for the assay of the alpha emission rate were first cut along the plane of the long axis using a grinding wheel. The cut surface of each half was placed on the sheets of the high-purity plastic α-detector, with about a 2 × 2 cm^2 area, as shown in Fig. 2a. The bone tablets were also placed on the sheets of the detector (Fig. 2b). The detectors with samples were sealed in a high-density polyethylene bag (to prevent the influx of radon) using a plastic bag heat-sealing machine and clamped in position, as shown in Fig. 2. The bag was placed inside the freezer at −20 °C for 120 days to 290 days to allow alpha particle tracks from the natural levels of activity in the teeth and bones to accumulate on the TASTRAK detectors. The temperature was measured using the HOBO Water Temp Pro (Tempcon Instrumentation, UK) with BoxCar Pro software 4.3. BoxCar software is supplied with logger to PC cable. In our technique, the alpha particles were measured without the chemical treatment of the samples using CR-39. At the end of the exposure period, the CR-39 detectors were then etched under controlled conditions in NaOH etchant solution as reported elsewhere (Almayahi et al., 2011, 2012a,b,c). The number of α-tracks per unit area for the tooth and bone samples was counted using an optical microscope (Olympus America Inc., System Microscope BX53) at 100× magnification.