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Measuring track density of alpha particles emitted from human teeth and assess of the resulting cancer risk

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ABSTRACT

Background: Since the radionuclides concentration in teeth is a good indicator of the human body's radioactive contamination, the purpose of this study was to measure the track density of alpha particles emitted from the human teeth and to assess the resulting cancer risk. ***Material and Methods:*** In this cross-section study, 93 permanent and unfilled tooth samples were collected from the patients residing in Khorramabad, Iran, and visiting dental clinics in this city. The alpha track density for the tooth samples was measured using CR-39 nuclear track detector. Annual effective dose (AED) and excess lifetime cancer risk (ELCR) were estimated based on the recommendations made by ICRP and UNSCEAR. ***Results:*** The mean alpha track density from ^{222}Rn in patients' teeth was410.15 tracks cm^{-2}, whereas the mean for women and men equaled 441.42 and 378.20, respectively. This difference was not statistically significant (P=0.22), but there was a statistically significant difference between the track densities in different age groups (P<0.001).In this study, the average radon activity concentration was 40.62 Bq m^{-3}. Also, the mean annual effective dose and the mean ELCR were calculated as 1.02 mSvy^{-1} and 3.59 ×10^{-3}, respectively. ***Conclusion:*** The AED value was higher than the permissible dose limit and also the mean ELCR was higher than the global average. Based on the results, it is necessary to perform periodical monitoring to detect pollution sources.

Keywords: *Human tooth, alpha particle, cancer risk, CR-39 detector.*

INTRODUCTION

The majority of human radiation exposure originates from natural sources (1). We annually receive some mSv of these radiations (2). Radioactive isotopes are present in our bodies and the environment. Environmental radioactive contamination can result in human exposure (3-4). ^{238}U, ^{232}Th series, ^{40}K, and their daughters are the main contributors to human internal radiation exposure from natural sources of radioactivity (5).^{226}Ra and ^{228}Ra isotopes are the most important radionuclides of ^{238}U and ^{232}Th series, respectively (6). The solubility of ^{226}Ra is higher than ^{238}U (1) and it is considered as the main source of radioactivity in various foods (7). This radioisotope (half-life of 1622 years) emits alpha particle, decays into ^{222}Rn (half-life of 3.8days) [1], and follows the process of calcium metabolism to accumulate in the bones (8). Moreover, 99% of the human body content of ^{226}Ra is stored in the bones (9). Exposure to high levels of this element in long periods of time can result in death and serious health effects, including anemia, cataract, and cancer (in particular, bone, liver, and breast cancer) (5).

^{218}Po and ^{214}Po from the Radon series, both of which are alpha-emitters, are the most important agents of the internal radiation to the lungs [10]. This type of radionuclide is ingested or inhaled and its half-life determines the radiation exposure to radionuclides in the body [5].

Teeth are developed from skeleton extension [11] and carry the footprint of human changes from the beginning of the first stage to the end of life [12]. Biologic crystals including hydroxyapatite $Ca_{10}(PO_4)_6(OH)_2$ form the mineral part of the tooth structure [13]. Teeth store radioactive contaminant elements which are bone-seeking, after they enter the body [11]. The concentration of radionuclides in the teeth and bones can indicate the rate of radioactive contamination of the body [14-15]. There is sufficient evidence to declare alpha-emitting internal radionuclides as carcinogenic and some radionuclides such as radon series are known to be carcinogens in humans [16].

Alpha particles with their dense ionization have higher relative biologic effectiveness than radiations such as X and gamma rays [17]. These particles spend all their energy on ionization and can cause chemical and biological changes [18]. CR-39 nuclear track detectors are employed in various fields of science and technology such as radon monitoring and alpha identification in order to measure the natural radioactivity of alpha particle in human tissues [19-21]. When the detector is exposed to heavy charged particles, such as alpha, comprehensive ionization occurs in its structure and breaks the polymer's chemical bonds. In this way, the permanent footprint of the radiation path remains in the detector structure [22]. In the presence of complex fields, only alpha particles are recorded because solid-state nuclear track detectors are completely insensitive to beta particles and gamma rays. The same feature avoids the problem of high background radiation that is encountered in other detectors [23]. Accordingly, the present study was aimed to measure the track density of alpha particles emitted from the human teeth and calculate the effective dose and cancer risk based on the recommendations made by ICRP and UNSCEAR organizations.

MATERIALS AND METHODS

This cross-section study was conducted in the summer of 2018 in Khorramabad, Iran, and was approved by Ethics Committee of Tehran University of Medical Sciences (TUMS), Iran (IR.TUMS.SPH.REC.1397.287).

The alpha track density for the tooth samples was measured using a CR-39 nuclear track detector (PADC Track Analysis Systems Ltd., UK) with the 25×25 mm area. The study was conducted on 93 permanent and unfilled tooth samples of 47 females and 46 males (the age range of 14-65 years old) collected from dental clinics across Khorramabad. The samples were extracted from the patients with dental diseases or for orthodontic purposes by dentists working in the city clinics. The participants in the present study were non-smokers living in Khorramabad who were born in this city and spent the entire period of their growth and calcification of their teeth there. Sample information, including age, sex, and number of teeth, was recorded by the researcher. Using the method described in the study conducted by Almayahi *et al.* (2014) [24], the extracted teeth samples were prepared and sterilized in 10% formaldehyde solution (in order to prevent spoilage of the samples) separately. In order to clean the samples of organic materials and soft tissue, they were washed with a brush and distilled water. Then, they were dried at 100°C in the oven for 2 h (figure 1). In the next step, by making a longitudinal cut, each sample was divided into two halves using a Micromotor set (SDE-SH37L) with dental finishing polishing discs in the dental laboratory. Subsequently, the cutting surface of both halves was placed in contact with both sides of the detector and fixed using adhesive tape and plastic strip. Each sample was placed in a high-density polyethylene bag to prevent the penetration of radon gas and sealed for a period of 115 days in a freezer at -20°C to establish secular equilibrium between radon and its daughters.

At the end of this radiation period, all of the 94 detectors were wrapped in their protective aluminum foils and Zip Kips and, then, delivered

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to Reference Radon Lab, Central Research Laboratory, Mazandaran University of Medical Sciences. In the laboratory, the detectors were etched using method of chemical etching in NaOH etchant solution (6.25 M) for3h at 85 °C. Afterwards, the number of alpha particle tracks per unit area of the detector was counted by an automatic alpha particle counter system equipped with a mechanical and electronic system, controlled entirely by a computer. The counting system took 30 microscope images from each CR-39 film and the number of alpha particles (tracks) was then changed to radon concentration in Bq.m^3 using calibration and conversion factors (the calibration factors of the detectors were previously determined by Atomic Energy Organization of Iran).

The radioactivity concentration of radon-222 (C) was calculated by equation1:

$$C\ (Bq\ m^{-3}) = (\rho - \rho_b)\ /kt \qquad (1)$$

Where ρ and ρ_b are the number of alpha tracks of the samples (track cm^{-2}) and the number of background tracks in the CR-39 detector, respectively, k is the conversion coefficient of0.0878 track cm^{-2}Bq^{-1} day^{-1}m^{3}used to convert alpha track density into radon radioactivity concentration, and t is the exposure time (days). The background track density analysis was performed on a blank detector stored alone.

Figure 1. Samples dried at 100°C for 2h.

In this study, the annual effective dose (AED) was calculated by equation 2 [25]:

$$AED\ (mSvy^{-1}) = C \times F \times O \times T \times DCF \qquad (2)$$

where C is the radon radioactivity concentration, F is the Rn-222equilibrium factor indoors recommended to be 0.4, O is the indoor occupancy factor (0.8), T is the indoor occupancy time (8760hr/yr), and DCF is the dose conversion factor recommended to be 9×10^{-6}mSvh^{-1}(Bqm^{-3})$^{-1}$by UNSCEAR [26].

In the next step, the excess lifetime cancer risk (ELCR) was estimated using equation 3, as follows [27]:

$$ELCR = AED \times DL \times RF \qquad (3)$$

in which AED denotes the annual effective dose, DL represents the duration of life (70 years), and RF indicates the fatal cancer risk factor (0.05 Sv^{-1} for public exposure).

Statistical analysis

Analytical and descriptive statistics was performed in SPSS software (ver.25); SPSS Inc, Chicago, USA).

RESULTS

The alpha track density in the tooth samples was determined (figure 2). The mean background alpha track density at different points of the detector equaled 52.31 track cm^{-2} in this study. Furthermore, the mean alpha track density in the samples was 410.15±248.98 track cm^{-2}, as presented in table 1.

The average alpha track density in the female teeth was 441.42±276.29 track cm^{-2}, whereas it was378.20±215.95 track cm^{-2}in the male teeth, as demonstrated in table 2. This difference was not statistically significant (P=0.22). A similar result for excess lifetime cancer risk was obtained because a linear relationship existed between alpha track density, radioactivity concentration of radon, annual effective dose, and excess lifetime cancer risk.

The results in Table 3 illustrate statistically significant differences between the mean alpha track density in the age groups (P<0.001). The

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mean alpha track density was observed to be minimum (235.06±91.42 track cm^{-2}) for the donors aged 50 years old and above.

A similar result was obtained for the radioactivity concentration of radon, annual effective dose, and excess lifetime cancer risk because a linear relationship existed between alpha track density and these variables.

In the female donors aged <30 years old, the alpha track density values were observed to be statistically significantly lower than those of the 30-49-year-oldage group (P=0.03) figure 3).Furthermore, in the male donors aged <30 years old, the alpha track density values were observed to be statistically significantly higher than those of the female donors of the same age (P=0.01).

In the male subjects aged 50 years old and above, the alpha track density values were observed to be lower than those of the other age groups (P<0.001).

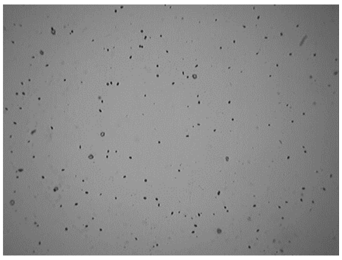

Figure 2. Alpha track density on CR-39 of a typical tooth sample.

Table 1. The Alpha Track Density Emitted from Human Teeth and the Resulting Excess Lifetime Cancer Risk

	Mean ±SD
Alpha track density (track cm^{-2})	410.15±248.98
Radioactivity concentration of radon-222 (Bq m^{-3})	40.62±24.65
Annual effective dose (mSvy^{-1})	1.02±0.62
Excess lifetime cancer risk ×10^{-3}	3.59±2.18

Table 2. Results of alpha track density and excess lifetime cancer risk by gender.

	Gender		P-value
	Female	Male	
	Mean±SD	Mean±SD	
Alpha track density (track cm^{-2})	441.42±276.29	378.20±215.95	0.223
Radioactivity concentration of radon-222 (Bq m^{-3})	43.71±27.36	37.45±21.38	0.222
Annual effective dose (mSvy^{-1})	1.10±0.69	0.94±0.54	0.222
Excess lifetime cancer risk ×10^{-3}	3.86±2.42	3.31±1.89	0.222

Table 3. Results of Alpha Track Density and Excess Lifetime Cancer Risk by Age.

	Age category			P-value
	< 30 Mean±SD	30 - 49 Mean±SD	≥ 50 Mean±SD	
Alpha track density (track cm^{-2})	459.65_a±275.57	486.99_a±245.14	235.06_b±91.42	<0.001
Radioactivity concentration of radon-222 (Bq m^{-3})	45.52_a±27.29	48.22_a±24.27	23.28_b±9.05	<0.001
Annual effective dose (mSvy^{-1})	1.15_a±0.69	1.22_a±0.61	0.59_b±0.23	<0.001
Excess lifetime cancer risk ×10^{-3}	4.02_a±2.41	4.26_a±2.14	2.06_b±0.80	<0.001

a,b: Values in the same row and sub-table not sharing the same subscript are significantly different at P< 0.05 in the two-sided test of equality for column means.

Table 4. Analysis of variance results of the alpha track density for age groups.

Source of variation	Sum of Squares	Degrees of freedom	Mean Square	F ratio	p-value
Between Groups	1060798.411	2	530399.205	10.283	<0.001
Within Groups	4642167.186	90	51579.635		
Total	5702965.597	92			

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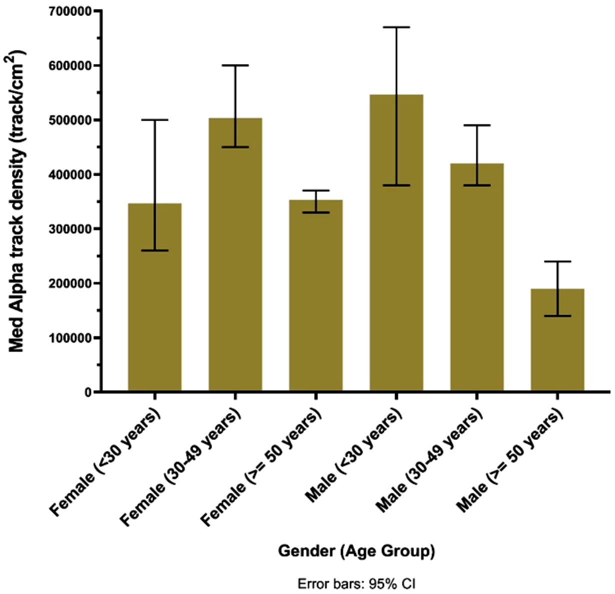

Figure 3. Alpha track density versus gender and age group.

DISCUSSION

^{226}Ra and ^{222}Rn (from the ^{238}U decay chain) and ^{228}Ra (from the ^{232}Th decay chain) have demonstrated a greater effect than other radionuclides on the human health (28). Radioactive substances transmitted into the body can accumulate in certain parts and cause internal radiation exposure (29). Therefore, it is of great importance to monitor the presence of radionuclides in some human tissues and organs (30).

In the present investigation, the mean radioactivity concentration of ^{222}Rn was estimated to be 40.62Bq m^{-3} which was lower than the reference level (100-300 Bqm^{-3}) recommended by ICRP (31). Based on table 1, the calculated value of mean annual effective dose was below the global average of 1.15 mSvy^{-1}(2) and mean ELCR wasapproximately2.47 times higher than the global average of 1.45×10^{-3} (26).

Based on our results, the mean alpha track density in the samples was 410.15±248.98 track cm^{-2}. In the study in Malaysia, Almayahi et al. used CR-39 and found the mean alpha track density of 634 and 619.62 track cm^{-2} in mice and chicken bones, respectively [32]. In another study, Almayahi *et al.* found the mean alpha track density of 153 and 544 track cm^{-2}in the human teeth and animal bones, respectively (24); in tooth samples, it was about 2.6 times lower than what we found in the present study. Furthermore, Almayahi *et al*. measured the average alpha track density in the human teeth in Iraq, which equaled 489.9 track cm^{-2} (33) and was higher than the findings reported in our work.

It was found that there is no significant effect for sex on the mean alpha track density in the human teeth. However, the mean alpha track density in the male teeth was slightly lower than that in the female teeth. This difference may be due to dietary habits and interactions with the environment. In contrast, Almayahi *et al.* found that sex had no significant effect on the alpha emission rates in the extracted human teeth (32). Similar to the results obtained in the present investigation, in another study by Almayahi *et al.*, the mean alpha emission rates in the male teeth were slightly higher than those in the female teeth; but, the difference was not statistically considerable (24).The findings of the study by Gholizade *et al.* demonstrated no considerable difference between the radioactivity concentration of ^{210}PO, an alpha-emitting radionuclide from the^{238}U decay chain, in female and male teeth (34).On the other hand, Task *et al.* found that the gross alpha radioactivity level was higher in the male donors' tooth samples than those of the female donors (30).

In this study, the mean alpha track density was observed to be minimumfor the donors aged 50 years old and above. This can be the result for the decline in skeletal growth in this age, as the site of the body where alpha-emitter elements are stored. Osteoporosis and bone fractures are among the most prevalent geriatric syndromes, the risk of whichincreases with age (35-37). In contrast to our observations, Almayahi *et al.* found no statistically significant difference between alpha emission rates in the age groups (24). In the study conducted by Taskin *et al.*, a slight decline was reported in the gross alpha level for male and female donors over the age of 45 years old (30). In another study, gross alpha activity concentrations were found and compared to changes in calcium in the human teeth. Based on the results, the gross alpha activity concentrations had different amounts for

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those under and over 18 years of age [38].

Relatively similar to the results obtained in the present investigation, Taskin *et al.* reported that in the female donors' in the 19- to 30-year-old age category, the average levels of gross alpha radioactivity were lower than those of the other age categories [30]. This can be explained by the fertility age of females [38, 39] and their physiological and hormonal conditions [30] during this period because the amount of calcium, which has a direct relationship with alpha particles, significantly declines in women during their fertility period [39-40]. Furthermore, in the study by Omer *et al*., the amount of Ca had an increase in the 19- to 25-year-old males, while there was a decline in females of the same age group. In addition, there was an increase in female donors aged over 19-25 years old [38].

CONCLUSION

Based on the findings obtained here, the mean annual effective dose was higher than the global average and also the mean ELCR was approximately 2.47 times higher than the global average. Therefore, it is necessary to perform periodical monitoring to detect pollution sources. Moreover, sex was found to have no significant effect on the mean alpha track density in human teeth, but mean alpha track density differed for different age groups.

Conflicts of interest: *Declared none.*

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