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Suitability of Japanese wild boar tooth enamel for use as an Electron Spin Resonance dosimeter

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ABSTRACT

The objective of this study was to determine the suitability of Japanese wild boar tooth enamel to evaluate lifetime radiation doses using Electron Spin Resonance Dosimetry (ESR). The opportunity to utilize tooth enamel of Japanese wild boar as a dosimeter is of particular interest due to their importance in the ecosystem within the Fukushima Exclusion Zone. Relevant characteristics were investigated which included the degree of linearity and variability in dose response of wild boar tooth enamel in the range of 1.2–12 Gy. The tooth enamel was found to have a linear dose response in this range. Teeth harvested from the same boar exhibited a variation in dose response ranging from 3.4 to 79.9%. Tooth enamel from deciduous teeth of young boar exhibited greater uniformity in radiation dose response than permanent tooth enamel taken from old boar. This finding suggests that the additive dose method would be more appropriate for performing precise dose reconstructions using tooth enamel of old boar. Preliminary results for retrospective doses varied between 0.2 and 1.4 Gy. Critical level and decision level doses were calculated for the samples used in this study, and values suggest that this methodology would be best utilized for wild boar with estimated absorbed doses exceeding 1 Gy. Information obtained during this study will be used with data collected in future studies to determine the suitability of wild boar tooth enamel for use with ESR dosimetry.

1. Introduction

The nuclear accident that occurred on March 11, 2011 at the Fukushima Daiichi Nuclear Power Plant as a result of the Great East Japan Earthquake and subsequent tsunami, caused the release of vast amounts of radioactive materials which were spread across large areas of Japan (Koarai et al., 2016). Radioactive contamination is still present, resulting in the chronic exposure of wildlife to low levels of radiation in an area of Japan known as the Fukushima Exclusion Zone. Of particular interest in this area is the effect of chronic low dose exposures to the Japanese wild boar, which are of utmost importance within the ecosystem of this region.

An obstacle often faced in the field of radioecology is the estimation of absorbed doses in wildlife exposed to radiation in the absence of conventional dosimeters. Alternate methods must be developed and used in such situations, to reconstruct exposures for use in understanding and predicting biological outcomes. Electron Spin Resonance (ESR) dosimetry, utilizing teeth as dosimeters, has been shown to be an effective method for determining absorbed dose in humans, using primarily adult permanent teeth, for a number of historical radiological accidents, as summarized by IAEA (2002) and Fattibene and Callens (2010). The potential for use of animal teeth as dosimeters using ESR has also been investigated in studies such as those by Khan et al. (2003), Serezhenkov et al. (1996), Klevezal et al. (1999), and Toyoda et al. (2003). More research is needed to confirm the appropriateness of teeth from different animal species and their ability to provide reliable measurements of absorbed doses in wildlife. The present study was conducted to investigate the dose response of tooth enamel from Japanese wild boar (*Sus scrofa leucomystax*) with the goal of establishing suitability for use as a dosimeter with ESR dosimetry.

2. Materials and methods

This study was reviewed by the Colorado State University Institutional Animal Care and Use Committee and was deemed to be exempt from oversight.

2.1. Tooth samples

Mandibles were procured from four Japanese wild boar living in

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various areas within the Fukushima Exclusion Zone. Wild boar in the Exclusion Zone are being culled by hunters at the behest of the Japanese Government to prevent destruction and invasion by the creatures. Mandibles were collected and taken to the laboratory at the Institute of Environmental Radioactivity at Fukushima University for processing. Pertinent data was recorded for each tooth sample extracted from the mandibles including: collection location, approximate age and sex of the boar from which the sample was taken, date of collection, and unique sample identification number.

2.2. Tooth extraction

Mandibles were stored in a freezer, under environmentally stable conditions, until the start of the sample processing procedure. Frozen mandibles were thawed overnight prior to processing. A low-speed water-cooled 10.16 cm (4-inch) saw (Ameritool, Inc., Redding, CA) with a diamond blade was used to carry out the crown amputation of molars and pre-molars. After tooth specimens were harvested, they were submerged in a 1–5% Sodium Hypochlorite solution for 24 h for the purpose of sterilization.

2.3. Sample selection

A subset of eight tooth samples were selected to determine linearity and variation in ESR dose response. Samples were selected from boar of different ages and from different positions within the mouth. Table 1 shows the sample number, tooth position, as well as the age of the boar for each of the samples selected. Boar ages were estimated by an experienced wildlife biologist using eruption and wear patterns in the teeth. An estimate of accumulated lifetime dose based on the boar's age and the dose rate at the collection site at the time of collection is also included. Although attempts were made to properly classify tooth specimens used, uncertainty in the age of the boar and tooth developmental stages created the potential for misclassification of tooth position. This does not impact the validity of the results shown, as both molars and pre-molars have been found to be useful with ESR dosimetry (International Atomic Energy Agency, 2002).

2.4. Sample preparation

The selected tooth samples were rinsed in acetone and placed in deionized water for a period of 24 h. Once the samples were removed from the deionized water, they were cut into smaller pieces using the water-cooled saw to aid in removal of dentin from the tooth enamel.

Dentin removal was performed using a combination of chemical and mechanical separation. First, a dental drill with water-cooling was used to remove as much visible dentin as possible from each tooth segment. Tooth segments were then placed in beakers containing a solution of 20% Potassium Hydroxide (KOH) for 24 h. Tooth specimens were removed from the solution and rinsed with deionized water. A water-cooled dental drill was again used to remove visible dentin. This process was repeated twice. Remaining enamel was rinsed in a solution of 70% Ethanol and dried at 40 °C in an oven for a period of 4 h.

An agate mortar and pestle were used to grind the dried enamel segments into a powder. Because the ideal grain size for ESR analysis is between 0.10 and 1.00 mm (International Atomic Energy Agency, 2002), a system of calibrated sieves was used, which consisted of a 1.00 mm sieve, a 0.50 mm sieve, and a 0.177 mm sieve. The powder enamel was poured through the series of sieves, and the material remaining between the sieves measured between 0.177 and 1.00 mm. Enamel larger than 1.00 mm was further crushed until the desired particle size was achieved. Powder enamel samples were then placed into plastic vials and stored at room temperature awaiting further processing. This step additionally served the purpose of allowing time for spurious signals, which may have been created as a result of sample processing, to fade (International Atomic Energy Agency, 2002).

Table 1
Summary of tooth samples selected for irradiation. Linear regression data including R^2 and dose response (slope) values from irradiated tooth sample measurements and differences in slope values for the right versus left tooth from the same boar are listed. Retrospective (intercept) doses for samples in this study with their associated uncertainty are also shown. Critical level doses (D_{CL}) and detection limit doses (D_{DL}) for each sample were calculated using methodology in Fattibene et al. (2011).

Sample Number	Estimated Age (Weeks)	Collection Site	GPS Coordinates	Collection Site Dose Rate (μGy/hr)[b]	Tooth Position	Linear Equation of Trendline	Slope ± σ	% Variation relative to the average	Average Slope by boar ± σ	R^2 Value	Estimated Lifetime Dose (Gy)[d]	Retrospective Dose ± uncertainty (Gy)	D_{CL} (Gy)	D_{DL} (Gy)
Ba20170608	30	Namie	N37.48922, E140.99678	0.34	P_{3R}	y = 138.27 × - 31.43	138.27 ± 4.12	11.48	130.76 ± 5.34	0.99	0.0017	[e]	0.9	1.6
					P_{3L}	y = 123.25 × - 52.04[c]	123.25 ± 6.33			0.98[c]		[e]	1.5	2.7
Ba20170609	> 220	Namie	N37.46531, E 140.92621	8.1	M_{3R}	y = 110.41x + 84.26	110.41 ± 3.15	27.14	97.22 ± 3.43	0.99	0.2994	0.8 ± 0.2	0.8	1.5
					M_{3L}	y = 84.02x + 116.15	84.02 ± 3.69			0.99		1.4 ± 0.3	1.3	2.3
Ba20170615[a]	> 220	Fukushima	N37.76129, E140.49994	0.46	M_{2R}	y = 36.74x + 18.26	36.74 ± 1.52	79.98	61.23 ± 3.11	0.99	0.017	0.5 ± 0.3	1.2	2.2
					M_{2L}	y = 85.72x + 14.81	85.72 ± 4.13			0.99		0.2 ± 0.3	1.4	2.6
Ba20170617[a]	26	Soma	N37.75646, E 140.98490	0.09	P_{3R}	y = 130.99× - 29.603	130.99 ± 5.23	3.44	133.29 ± 3.83	0.99	0.0004	[e]	1.2	2.1
					P_{3L}	y = 135.58x + 12.99	135.58 ± 1.40			0.99		[e]	0.2	0.5

[a] Control boar tooth sample.
[b] Based on measurements made using a Hitachi TCS-172 NaI Scintillation Survey meter at the site of capture.
[c] Average spectral data values for Ba20170608 P_{3L}, Sample 6 were calculated using Microsoft Excel.
[d] Based on dose rate and age of boar, assuming negligible contribution from internally deposited nuclides.
[e] Projected doses approach zero.

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