Applied Radiation and Isotopes 139 (2018) 86–90

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

Effect of the tooth surface water on the accuracy of dose reconstructions in the X-band in vivo EPR dosimetry

Jierui Zou, Junwang Guo, Guofu Dong, Lei Ma, Jianbo Cong, Ye Liu, Ye Tian, Ke Wu*

Beijing Institute of Radiation Medicine, Beijing Key Laboratory of Radiation Biology (No. BZ0325), China

HIGHLIGHTS

- X-band EPR signal of tooth enamel is measurable in the presence of some tooth surface water.
- The EPR cavity sensitivity decreases with increasing thickness of the tooth water layer.
- Normalization to the reference sample signal effectively reduces the error.

ARTICLE INFO

Keywords:
EPR tooth dosimetry
In vivo
Surface water

ABSTRACT

The X-band in vivo EPR tooth dosimetry is promising as a tool for the initial triage after a large-scale radiation accident. The dielectric losses caused by water on the tooth surface (WTS) are one of the major sources of inaccuracies in this method. The effect was studied by theoretical simulation calculations and experiments with water films of various thicknesses on teeth. The results demonstrate the possibility of sufficiently accurate measurements of the radiation-induced signal of the tooth enamel provided that the thickness of the water film on the tooth is below 60 µm. The sensitivity of the cavity decreases with increasing thickness of the water layer. The interference of WTS can be diminished by normalization of the radiation-induced signal to the signal of a reference sample permanently present in the cavity.

1. Introduction

The electron paramagnetic resonance (EPR) tooth dosimetry is a physics-based biodosimetric technique widely recognized as an attractive approach to an initial triage of victims after an unexpected large-scale radiation accident (Fattibene and Callens, 2010; Flood et al., 2014; Swartz et al., 2014). However, the conventional X-band EPR dosimetry has so far been successfully used only for long-term retrospective analysis and certification of doses in vitro. The reason for that is that the dosimetry requires extracting teeth and taking measurements in a special laboratory (Chumak et al., 2005; Zhumadilov et al., 2007; Nakamura et al., 2012; Wieser, 2012).

In the recent years, in vivo tooth EPR dosimetry was being developed, which is very promising as a tool for triage in large-scale radiation incidents (Swartz et al., 2007; Flood et al., 2016). Ikeya and Ishii, (1989) laid out the general conceptual approach to the in vivo EPR dosimetry. However, the initial results of using the X-band EPR for the in vivo dosimetry were barely satisfactory because of the poor sensitivity of the instruments and, in particular, the inefficient design of the in vivo cavity. Swartz and his colleagues (Swartz et al., 2005; Iwasaki et al., 2005; Williams et al., 2011; Ivannikov et al., 2016) conducted a series of studies in that area using the L-band EPR and made reasonable progress. The lower frequency of the L-band makes it easier to overcome the detrimental effect of the dielectric losses by water in the mouth. Theoretically, the X-band EPR can provide higher sensitivity. However, higher microwave dielectric losses caused by water in the mouth at this frequency are one of the most important reasons to question the feasibility of the X-band EPR in the vivo tooth dosimetry (Yamanaka et al., 1993; Ke et al., 1996; Miyake et al., 2000). In our previous work, we developed specially designed cavities for in vivo tooth measurements with the X-band EPR (Junwang et al., 2013, 2014; Guo et al., 2015, 2016). The cavities were made to accommodate only the cusps of incisors, which could be inserted into their detection apertures to ensure that the primary signaling component is the enamel, generally free of interference caused by water in the oral soft tissue and dentin. Nonetheless, that did not resolve the problem of the interference of the water on the tooth surface (WTS), which severely impacted measurements of the radiation-induced signal (RIS) of the tooth in practical applications. There are few published data that could be useful for a resolution of this problem.

* Correspondence to: Beijing Institute of Radiation Medicine, Beijing Key Laboratory of Radiation Biology, No.27 Tai Ping Road, Beijing 100850, China.
E-mail address: wuk315@163.com (K. Wu).

https://doi.org/10.1016/j.apradiso.2018.04.030
Received 25 October 2017; Received in revised form 23 April 2018; Accepted 23 April 2018
Available online 24 April 2018
0969-8043/

This aim of this work was to investigate the effect of WTS and lay a foundation for more accurate signal measurements in the practical applications of the in vivo EPR tooth dosimetry. Theoretical simulations and experimental measurements were used to analyze the effect of the tooth surface water films of various thicknesses. As a result, some insight has been gained into a possible solution of the problem. Besides, some other issues unrelated to the microwave dielectric losses, but still contributing to the uncertainty of results in the X-band EPR in vivo dosimetry are also discussed.

2. Methods and results

2.1. The X-band in vivo EPR dosimetry system

In this work, all experiments were performed on a homemade X-band EPR spectrometer for in vivo tooth measurements. It worked at a frequency of 9.5 GHz with a magnet that had a relatively large gap for in vivo use. The system included a specially designed cavity with a detection aperture that accommodated only the cusp of an incisor, a pair of modulation coils set separately outside of the cavity, an alternating current power amplifier for driving the field modulation, a phase-locked amplifier signal receiver, as well as data acquisition and processing units.

2.2. Reference sample

An internal reference sample containing Mn^{2+} in CaO incapsulated in a thin quartz capillary was attached in a hole near the detection aperture (Fig. 1). The signal of the reference sample could be measured synchronously with the signal of the tooth. The lines of Mn^{2+} and RIS of the tooth were included in a single scan of a reasonable width where the two signals were sufficiently separated (Sholom et al., 2005; Tikunov et al., 2005). The signal amplitude of the reference sample was controlled by adjusting the total amount of the sample.

2.3. Experimental estimation of the thickness of the WTS coating

To evaluate the range of thicknesses of WTS coating under usual conditions and to get a guidance for making the water film models in the next step, the thickness of the WTS coating was estimated by measuring the weights of a tooth before and after its soaking in water. The thickness of the WTS coating was then roughly estimated by dividing the weight increase by the surface area of the tooth and the density of water. Five teeth with good surfaces and no apparent holes were used, and five parallel experiments were made with each of them. The thickness range was found to be 39.6–79.2 μm. The variations were mainly due to differences in the smoothness, shape and size of the teeth.

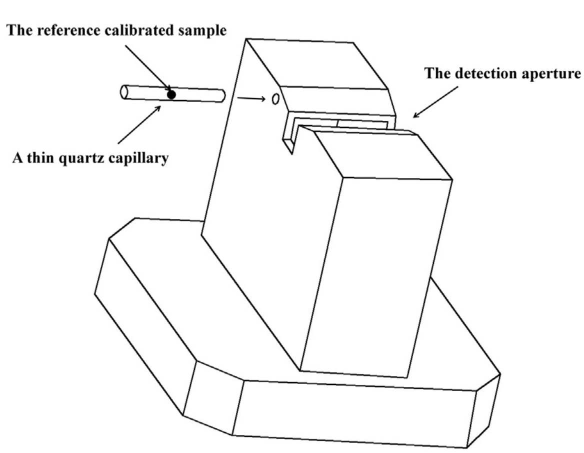

Fig. 1. The geometry of the cavity hosting an internal reference calibration sample.

2.4. Models of the water film

In order to reasonably simulate the effects of WTS, we constructed a series of the thin water film models with different thicknesses. As the detection area was only on the cusp of the incisor in our EPR dosimetry system, water in the oral soft tissues and dentin was neglected. Fig. 2 summarized the manufacturing procedures. First, two identical pieces of a polythene thin film were sealed with a thermoplastic sealing machine to form a pouch. Then, a varying volume of water was injected into the pouch with a pipette to control the thickness of water film that could be computed by dividing the volume of the water by the effective area of the film (this area was kept constant). Finally, the air was squeezed out of the pouch, and the pouch was sealed to form a continuous water film and attached to the tooth surface or a free radical point sample.

2.5. Theoretical simulation of the effect of WTS

The effect of WTS on the cavity quality factor (*Q*-factor) was simulated by a finite element calculation based on HFSS (a microwave simulator by the ANSYS Corp.). In the model, the incisor was represented by a wedge to simplify the calculation (Fig. 3). The simulation used the following parameters: cavity length 22 mm; cavity height 21.4 mm; cavity width 10 mm; silver as the boundary material of the cavity; air is the filling dielectric; detection aperture size $10 \times 2.5\ mm^2$; eigenmode; parameter sweep analysis; the thickness of water on the tooth surface as the sweep parameter; linear sweep from 0 to 100 μm in 1-μm steps; the resonance quality factor of the cavity as the result.

Fig. 4 shows results of the finite element simulation of the *Q*-factor of the cavity vs. the thickness of WTS. There is a downward trend of the *Q*-factor with increasing water thickness, which decreases the detection sensitivity. It is in line with the results of experimental measurements described below.

2.6. Measurements of the signal of the free radical point sample

To verify the validity of the experiment with real teeth and to get more information, measurements of the signal of a free-radical point sample were also taken in parallel with the experiments involving teeth. DPPH (1,1-Diphenyl-2-picrylhydrazyl radical 2,2-Diphenyl-1-(2,4,6-trinitrophenyl) hydrazyl) powder was inserted into a quartz capillary of 1 mm in diameter to form a stable point sample. The point sample was wrapped with one of the various water films and then attached in the center of the detection aperture. The thicknesses of the used water films were 0, 20, 40, 60, 80 μm (0 μm meant an empty film pouch). The typical parameters of the spectrum registration were: scan time 300 s; time constant 0.03 s; scan width 10 mT; microwave frequency 9.5 GHz; microwave power 1.2 mW; center magnetic field 0.34 T.

Fig. 5a shows spectra of the DPPH point sample wrapped in the water films of different thicknesses. The strong signal of DPPH could be observed even when at water thickness of 80 μm. The signal-to-noise ratio (SNR) for the DPPH signal was taken as the measurement sensitivity index. The SNR value of the DPPH point sample appears to decrease with increasing water thickness (Fig. 5b). However, the normalized signal intensity, which was defined as the ratio of the DPPH signal intensity to the reference signal intensity, remains almost constant (Fig. 5c) within the tested range of the thicknesses of WTS.

2.7. Measurements of the signal of tooth samples

Two isolated incisors with good surfaces and no apparent holes irradiated to 2 and 4 Gy with a ^{60}Co radiation source were used in the experiment. The cusp part of each tooth was wrapped in a water film before measurements. The position of the tooth in the aperture was