DIGITAL AUTORADIOGRAPHY OF BONE-SEEKING RADIONUCLIDES IN HUMAN

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This paper describes the ionizing-radiation quantum imaging detector (iQID) system and its applicability for imaging of bone-seeking alpha-emitters. The United States Transuranium and Uranium Registries (USTUR) studies actinide (plutonium, americium, and uranium) biokinetics and tissue dosimetry by following up occupationally exposed individuals. Estimation of the micro-distribution of radionuclides in tissues is an important task to support biokinetic modeling and dose assessment. A newly developed iQID system was used to study radionuclide distribution in human bones. Results showed that iQID imaging approach is proven to be an effective method for micro-scale heterogeneous distribution studies, where traditional counting methods do not apply.

IONIZING-RADIATION QUANTUM IMAGING DETECTOR

The ionizing-radiation Quantum Imaging Detector (iQID) is a newly developed digital autoradiography (radiation imaging) system[1]. The iQID allows for real-time quantitative autoradiography and study of radionuclide micro-distribution at a low radionuclide activity level ($<10^{-3}$ events per second). The iQID system is a portable, laptop-operated unit. Single-particle imaging with sub-pixel position estimation enables imaging studies to be performed at spatial resolutions as high as 20 µm. Large-area iQID configurations (up to 200 mm diameter) accommodate studies requiring simultaneous imaging of an array of samples. The high detection efficiency (50-100%), low background rate, and event-by-event spatiotemporal information allow activity distributions to be quantified, even with short-lived radionuclides.

The iQID is comprised of a scintillator in direct contact with a micro-channel plate (MCP) image intensifier and a lens for imaging the intensifier screen to a CCD or CMOS camera sensor, all within a compact light-tight enclosure. iQID is sensitive to a broad range of radiation including gamma-/X-rays, neutrons, spontaneous fission, conversion electrons, alpha and beta particles[1].

In order to localize the origin of a radioactive particle precisely, a iQID image is superimposed over the structural image of a sample. The iQID image carries information on the spatial distribution of radioactive particles, while a structural image represents a sample geometry. The structural digital image is acquired using a scanner, digital camera, or microscope.

FEASIBILITY STUDIES

The iQID system was used for microdosimetry of targeted radionuclide therapy using α- and β-emitters: ^{211}At, ^{90}Y, and ^{177}Lu in soft tissues[2]. At the USTUR, the application of iQID is successfully extended for imaging of bone-seeking α-emitters: ^{241}Am, ^{239}Pu, and ^{226}Ra in humans[3]. For the internally deposited radionuclides, activity distribution was visualized and quantified in various bone sections. Radionuclide activity distribution ranged between 0.002 and 0.003 mBq mm^{-2} for ^{239}Pu 0.1 and 0.7 mBq mm^{-2} for ^{226}Ra, and 1.0 and 10.0 mBq mm^{-2} for ^{241}Am. Mapping of radionuclide distribution was successfully achieved on a macro-scale. However, it was challenging to distinguish whether α-events originated from the surface or volume of a sample. The α-interference can be eliminated by preparing micron-thick slides. (Fig. 1).

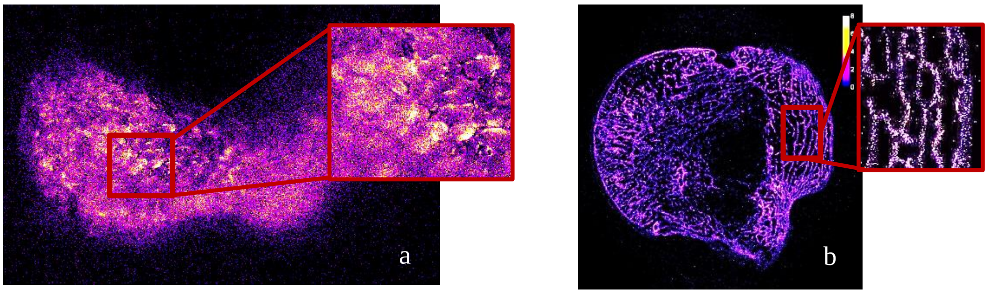

Fig.1. Distribution of ^{241}Am in clavicle acromial end (a) – unpolished bone surface, and in humerus proximal end (b) – polished 100-µm-thick slide.

BONE MICRO-DOSIMETRY

To study bone micro-dosimetry, bone specimens were sampled from humerus proximal end, humerus proximal shaft, and clavicle acromial end. These specimens were embedded in methyl methacrylate plastic and processed to produce multiple 100 µm-thick sections. Bone sections were polished to a fine surface.[4] This allowed to investigate distribution of metabolized ^{241}Am within trabecular bone regions on a micro-scale. The ^{241}Am activity distributions were visualized and quantified in cortical bone and trabecular spongiosa (Fig. 1b). The ^{241}Am activity concentration ratios within different bone regions were used to represent the radionuclide distribution. The trabecular-to-cortical bone and trabecular spongiosa-to-cortical bone rations are reported in Table I for the humerus and clavicle. The iQID values are in agreement with those obtained from radiochemical analysis but not consistent with the ICRP biokinetic model predictions.

TABLE I. ^{241}Am activity concentration ratios within different bone regions

Bone Region	Humerus Bone		Clavicle Bone		iQID/ICRP	
	iQID	α-spec	iQID	α-spec	Humerus	Clavicle
Trabecular-to-cortical	2.76 ± 0.04	2.15 ± 0.13	1.29 ± 0.15	1.48 ± 0.11	5.5	2.6
Spongiosa-to-cortical	1.09 ± 0.01	1.28 ± 0.08	0.65 ± 0.06	0.68 ± 0.05	5.5	3.3

CONCLUSIONS

The iQID digital imager allows for real-time visualization and quantitative digital autoradiography of bone-seeking alpha-emitters. To reduce a signal-to-noise ratio and improve an image resolution, appropriate sample preparation is required. The ^{241}Am micro-distribution measurements showed that ICRP defaults underestimate ^{241}Am concentration ratios within cortical bone regions at least by a factor of 3.

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