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) system¹. 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 particles¹. 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: ²¹¹At, ⁹⁰⁰Y, and ¹⁷⁷Lu in soft tissues². At the USTUR, the application of iQID is successfully extended for imaging of bone-seeking α-emitters: ²⁴¹Am, ²³⁹Pu, and ²²⁶Ra in humans³. 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 ²³⁹Pu 0.1 and 0.7 mBq mm⁻² for ²²⁶Ra, and 1.0 and 10.0 mBq mm⁻² for ²⁴¹Am. 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. 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 ratios 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>
<thead>
<tr>
<th>Bone Region</th>
<th>Humerus Bone</th>
<th>Clavicle Bone</th>
<th>iQID/ICRP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>iQID</td>
<td>α-spec</td>
<td>iQID</td>
</tr>
<tr>
<td>Trabecular-to-cortical</td>
<td>2.76 ± 0.04</td>
<td>2.15 ± 0.13</td>
<td>1.29 ± 0.15</td>
</tr>
<tr>
<td>Spongiosa-to-cortical</td>
<td>1.09 ± 0.01</td>
<td>1.28 ± 0.08</td>
<td>0.65 ± 0.06</td>
</tr>
</tbody>
</table>

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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REFERENCES