A Nuclear Medicine Network for In Vivo Monitoring of Workers Exposed To Iodine-131

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Abstract. Iodine-131 is still widely used in nuclear medicine for therapy and diagnostic and its manipulation in the form of liquid unsealed sources represents a significant risk of internal exposure to the workers involved in such practice. The most exposed workers are the ones who carry out a variety of wet operations such as dose fractionation, preparation of radiopharmaceuticals and administration to the patients. The internal monitoring of such workers is recommended by the IAEA for those who might be exposed to effective doses above 1 mSv per year. The number of exposed workers and the large amounts of activities manipulated routinely justifies the need for the development of feasible and non-expensive methodologies for routine internal monitoring. Such monitoring procedures can only be executed in a few Laboratories located in governmental institutions, which turns unfeasible to implement such control in a national basis. On the other hand, it can be executed in the nuclear medicine services by using their image diagnose equipment which are promptly available. The objective of this work is to establish a calibration protocol and an in vivo measurement procedure to evaluate incorporation of \textsuperscript{131}I using gamma câmeras and establish a nuclear medicine service network including 3 hospitals located in the city of Rio de Janeiro, Brazil. The calibration factors - necessary to calculate the activity deposited in the thyroid - of four gamma câmeras, installed at the Federal University (DIACAM and GE), State University (E.CAM) and Navy Hospital (E.CAM) were determined with a neck-thyroid phantom developed at the In Vivo Monitoring Laboratory of IRD. The results show that the gamma cameras can be used for routine monitoring of \textsuperscript{131}I since the minimum detectable effective doses for a standard count time of 10 minutes are below 1 mSv.

KEYWORDS: Internal monitoring; bioassay; neck-thyroid phantom; gamma camera.

1. Introduction

Several radionuclides are used in Nuclear Medicine. Among them, \textsuperscript{131}I is widely applied for diagnostic and therapeutic purposes. It is highly volatile and radiotoxic, which may represent an occupational radiological hazard, especially in places where significant activities are routinely manipulated. In such situations, workers who manipulate unsealed sources of \textsuperscript{131}I may be internally exposed by inhalation. According to the IAEA [1], handling of large quantities of radiopharmaceuticals, such as \textsuperscript{131}I for therapy is a situation in which experience has shown that it is necessary to give consideration to routine individual monitoring for internal exposure. However, when planning an internal monitoring program for nuclear medicine workers, a few factors with significant impact in cost and feasibility should be considered: high monitoring frequency for \textsuperscript{131}I [2], large number of workers involved in this professional activity, geographical dimensions of the country and transportation costs.

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131I is a short-lived radionuclide (half-life = 8 d). It decays by $\beta$ emission producing photons of 0.36 MeV [3]. The biokinetic model for systemic iodine suggested in ICRP 56 [4] is similar to that described in ICRP 30 [5]. For adults, it is assumed that, of the iodine reaching the blood, 30% is transported to the thyroid gland and other 70% is excreted directly in urine via the urinary bladder. The biological half-life in blood is taken to be 6 hours. Iodine incorporated into thyroid hormones leaves the gland with biological half-life of 12 days. Most iodine (80%) is subsequently released and is available in the circulation for uptake by the thyroid or direct urinary excretion; the remainder is excreted via the large intestine in the feces. Because of the short physical half-life of $^{131}I$, this recycling is not important in terms of the committed effective dose [1]. Iodine is rapidly absorbed into the circulation following inhalation or ingestion. It is concentrated in the thyroid and excreted predominantly in urine [4, 6].

A standard monitoring program for workers occupationally exposed to $^{131}I$ should be include direct thyroid measurement, indirect bioassay of urine samples and workplace monitoring [1]. However, due to the large number of Nuclear Medicine Services in Brazil and its distribution all over the country, it is unfeasible to establish a national monitoring program if the measurements are performed solely in laboratories located in the Institutes of the Brazilian Nuclear Energy Commission (CNEN). An alternative and inexpensive method to control internal exposure of the workers by in vivo monitoring is to use a gamma camera, which is available in most nuclear medicine centers.

This work presents the development and application of an anthropomorphic thyroid-neck phantom used for calibration and quality control of four gamma-cameras installed at the Federal University (DIACAM and GE), State University (E.CAM) and Navy Hospital (E.CAM) located in the city of Rio de Janeiro.

2. Materials and methods

**Calibration procedures.** The neck-thyroid phantom used for the calibration of the detection systems was designed and produced at the In Vivo Monitoring Laboratory of IRD [7]. It contains a known activity of $^{133}$Ba ($^{131}$I simulator) standard solution which has been uniformly distributed on the surface of a filter paper previously cut in the form and shape of a human thyroid (Figure 1).

**Figure 1.** Neck-thyroid phantom developed at IRD

The Gamma Cameras used in this work contains one high resolution rectangular NaI(Tl) detector. These equipments were calibrated with the IRD-Neck-Thyroid phantom for direct in vivo quantification of $^{131}$I in the thyroid. The calibration consisted on the determination of the ratio between the count rate recorded at the $^{131}$I window and the phantom activity. The calibration factors are expressed in cpm/Bq. This calibration were performed without the high-energy collimator, in order to increase sensitivity of the detection system up to a level suitable for internal monitoring of occupationally exposed workers.

The neck-thyroid phantom was positioned on the bed below the gamma camera and the measurements were performed at four distances: 10, 15, 20 and 25 cm. Just Navy hospital gamma camera’s were performed the calibration using two distances: 20 and 25 cm. A group of unexposed subjects was measured subsequently to determine the Minimum Detectable Activity [8] of the methodology. The MDA is defined as the smallest activity of radioactive material in a sample that will yield a net count, above of background, that will be detected with at least 95% probability. The counting geometry and
subjects counting time were optimized to produce minimum interference in the routine of the clinic. Figure 2 presents an in vivo measurement of a subject performed with the gamma camera (DIACAM) and the Figure 3 show the calibration performed using thyroid neck-phantom (\(^{133}\)Ba).

\[
MDA = \frac{4.65 \sqrt{BKG}}{FC \cdot t} + \frac{3}{FC \cdot t}
\]

(1)
where MDA = Mínimum Detectable Activity (Bq), BKG = Background measurement (cpm), FC = Calibration Factor (cpm/Bq) and t = count time (minutes)

**Figure 2.** In vivo measurement of thyroid performed with Gamma Camera, without high-energy collimator

**Figure 3.** Calibration measurement performed using thyroid neck-phantom

The values of Minimum Detectable Effective Dose (MDED) were calculated using the software AIDE (Activity and Internal Dose Estimates) [9], considering that the measurement would be carried 7 and 14 days after the intake. This software is based on the analytic resolution of auto-values and auto-vectors. It is used to calculate activities in organs and tissues of the human body and also to estimate the committed effective doses due to the intake of radionuclides using the bioassay data.

### 3. Results and discussion

Table 1 presents the results of the calibration procedure in terms of Calibration Factor, Minimum Detectable Activity and Minimum Detectable Effective Dose obtained for 10 minutes counting time by Gamma Camera DIACAM available at the Rio de Janeiro Federal University Hospital.

The Minimum Detectable Effective Doses for a 10-minutes thyroid monitoring performed 7 or 14 days after intake are far below the record level of 1 mSv for a single intake by inhalation of \(^{131}\)I vapor. Data obtained using Gamma Camera DIACAM.
Table 1: Calibration parameters of the gamma camera DIACAM

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Calibration Factor (cpm/Bq)</th>
<th>MDA* (Bq)</th>
<th>Minimum Detectable Effective Dose (x 10^{-2}) mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>2.35 ± 0.03</td>
<td>81</td>
<td>1.16</td>
</tr>
<tr>
<td>15</td>
<td>1.81 ± 0.02</td>
<td>106</td>
<td>1.51</td>
</tr>
<tr>
<td>20</td>
<td>1.28 ± 0.01</td>
<td>149</td>
<td><strong>2.12</strong></td>
</tr>
<tr>
<td>25</td>
<td>1.01 ± 0.01</td>
<td>189</td>
<td><strong>4.12</strong></td>
</tr>
</tbody>
</table>

*Minimum Detectable Activity (MDA) calculated for 10 minutes count time.

Table 2 presents the results of the calibration procedure in terms of Calibration Factor, Minimum Detectable Activity and Minimum Detectable Effective Dose obtained for 10 minutes counting time by Gamma Camera GE (Millenium) available at the Rio de Janeiro Federal University Hospital.

Table 2: Calibration parameters of the gamma camera GE (Millenium)

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Calibration Factor (cpm/Bq)</th>
<th>MDA* (Bq)</th>
<th>Minimum Detectable Effective Dose (x 10^{-2}) mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.65 ± 0.01</td>
<td>110</td>
<td>1.57</td>
</tr>
<tr>
<td>15</td>
<td>1.23 ± 0.01</td>
<td>148</td>
<td>2.12</td>
</tr>
<tr>
<td>20</td>
<td>0.95 ± 0.01</td>
<td>191</td>
<td><strong>2.72</strong></td>
</tr>
<tr>
<td>25</td>
<td>0.74 ± 0.01</td>
<td>246</td>
<td><strong>5.28</strong></td>
</tr>
</tbody>
</table>

*Minimum Detectable Activity (MDA) calculated for 10 minutes count time.

Table 3 presents the results of the calibration procedure in terms of Calibration Factor, Minimum Detectable Activity and Minimum Detectable Effective Dose obtained for 2 minutes counting time by Gamma Camera E.CAM available at the Rio de Janeiro State University Hospital.

Table 3: Calibration parameters of the gamma camera E.CAM

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Calibration Factor (cpm/Bq)</th>
<th>MDA* (Bq)</th>
<th>Minimum Detectable Effective Dose (x 10^{-2}) mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.82 ± 0.02</td>
<td>74</td>
<td>1.06</td>
</tr>
<tr>
<td>15</td>
<td>1.36 ± 0.01</td>
<td>99</td>
<td>1.41</td>
</tr>
<tr>
<td>20</td>
<td><strong>1.02 ± 0.01</strong></td>
<td><strong>132</strong></td>
<td><strong>3.64</strong></td>
</tr>
<tr>
<td>25</td>
<td>0.78 ± 0.01</td>
<td>172</td>
<td>2.46</td>
</tr>
</tbody>
</table>

*Minimum Detectable Activity (MDA) calculated for 10 minutes count time.
Table 4 presents the results of the calibration procedure in terms of Calibration Factor, Minimum Detectable Activity and Minimum Detectable Effective Dose obtained for 10 minutes counting time by Gamma Camera E.CAM available at the Rio de Janeiro Navy Hospital.

**Table 4:** Calibration parameters of the gamma camera E.CAM

<table>
<thead>
<tr>
<th>Distance (cm)</th>
<th>Calibration Factor (cpm/Bq)</th>
<th>MDA* (Bq)</th>
<th>Minimum Detectable Effective Dose (x 10⁻²) mSv</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>0.93 ± 0.01</td>
<td>137</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>±± ±± ±± ±± ±± ±± ±± ±± ±± ±±</td>
<td></td>
<td>14 days</td>
</tr>
<tr>
<td>25</td>
<td>0.69 ± 0.01</td>
<td>186</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td>±± ±± ±± ±± ±± ±± ±± ±± ±± ±±</td>
<td></td>
<td>14 days</td>
</tr>
</tbody>
</table>

*Minimum Detectable Activity (MDA) calculated for 10 minutes count time.

4. Conclusions

The results suggest that in vivo measurement frequencies of 7 or 14 days would be suitable for routine monitoring of $^{131}$I in the thyroid. The counting time should be 10 minutes using the gamma camera without collimator. Under these conditions the values of Minimum Detectable Effective Dose are all bellow 1 mSv considering incorporation by single intake of $^{131}$I in the form of vapor. This shows that the proposed technique is feasible and useful for the monitoring of individuals who manipulate unsealed sources routinely in Nuclear Medicine Services as well as in accident situations.

Acknowledgments

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REFERENCES