Evaluation of Portuguese population exposure to ionizing radiation due
to radiodiagnostic and nuclear medicine exams

Summary of dissertation for the Master degree in Radiation Protection and Safety

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Abstract: This work studies the Portuguese population exposure to ionizing radiation due to radiodiagnostic and nuclear medicine (NM) exams, between 2013 and 2017, using the methodology proposed in the Report Radiation Protection 154. This work shows that the radiodiagnostic exam that contribute the most to the collective dose in Portugal is the Computed Tomography (CT). It is also shown that the annual average effective dose of the Portuguese population due to radiodiagnostic exams has increased about 15%, from 0,79 mSv caput⁻¹ in 2013 to 0,91 mSv caput⁻¹ in 2017. Lower increment is registered when considering the nuclear medicine exams. Considering NM exams, the annual effective dose was 0,088 mSv caput⁻¹ in 2013 and 0,090 mSv caput⁻¹ in 2017, being the exams that contribute the most to the collective dose the bone imaging and cardiac exams. This study intends to raise awareness to the need of optimization of dose exposure in medical exams.

Introduction

Radiation may be classified in two main categories: ionizing radiation and non-ionizing radiation. Non-ionizing radiation, such as visible light, radio waves or microwaves, do not ionize matter. On the other hand, ionizing radiation, as gamma and x-rays, has the ability to ionize matter, therefore, it can be a health hazard [1].

In medicine, ionizing radiation is used in multiple fields that can be classified as: radiodiagnostic (uses low energy ionizing radiation in diagnostic medical imaging), nuclear medicine (uses radiopharmaceuticals to obtain diagnostic images or for therapeutic purposes) and radiotherapy (uses high energy ionizing radiation for oncology treatments).

Owing to the fast evolution of the technologies used in health, such as the medical equipment for diagnosis and treatment, nowadays it is possible to carry out exams and treatments that were unthinkable decades ago. Despite of the benefits for the patient, this technological evolution has been followed by a gradual increase to ionizing radiation exposure of patients, health professionals and general population. The use of ionizing radiation in medicine has increased in such a way that nowadays it is the main source of exposure from a non-natural origin, corresponding to 95% of that exposure [2,3].

Against this fact, many world organizations (IAEA – International Atomic Energy Agency; WHO – World Health Organization), as well as national and local authorities (DGS – Direção Geral de Saúde and IST – Instituto Superior Técnico, in Portugal), have insisted on a growing effort to develop a sturdy methodology to allow to estimate population dose in what concerns the execution of medical exams.
involving the use of ionizing radiation [4,5]. Thus, the European Commission, in order to harmonize the dose calculation for their member states, published a document entitled “European Guidance on Estimating Population Doses from Medical X-Ray Procedures” also known as the Radiation Protection 154 document (RP 154) [6]. This document provides a harmonized system with recommendations and methodologies to determine the collective dose exposure in adult population due to medical procedures (both radiology and nuclear medicine).

Additionally, in order to facilitate population exposure determination due to radiodiagnostic and nuclear medicine practices, RP 154 document defines 20 exams (TOP 20) in the radiology field (that includes radiography, fluoroscopy, computerized tomography and intervention exams) that contribute the most to collective effective dose. These exams comprise 50% to 70% of the total of carried out exams and 70% to 90% of total collective effective dose due to radiodiagnostic exams. In Nuclear Medicine’s case the 28 most common procedures are considered, divided in six types of exams that involve the administration of radiopharmaceuticals [5-7].

In Portugal, despite the European and national recommendations, and in spite of what is observed in other countries, there are no solid studies to periodically evaluate the population exposure due to radiodiagnostic and NM exams.

Therefore, the development of population exposure evaluation studies to ionizing radiations due to medical exams, like the one presented, allow to fill in the persistent lack of studies like this in the country. The results obtained, that comprise data from 2013 to 2017, will allow to keep up with other countries in the development of representative studies of periodical evaluation of dose exposure in population in the scope of medical exams, enabling to compare per caput dose per exam, frequencies per exam, as well as to perform a critical comparative analysis to justify and optimize the exams carried out in Portugal.

The present work also aims to cooperate with the Diagnostic Reference Levels (DRL) Portugal Project [8], supplying data to establish the national DRL for the most frequent procedures per genre of medical image that uses ionizing radiation. The DRL establishment at national level aims to harmonize practices and promote the optimization of medical exposures.

**Materials and Methods**

In this work, to study the exposure of the Portuguese population to ionizing radiation due to radiodiagnostic and NM exams, the methodology described in the RP 154 [6] has been followed. The TOP 20 of radiodiagnostic exams and twenty eight exams of nuclear medicine have been considered. The NM exams are divided in six groups, however, for this study, were considered seven: bone, cardiac, thyroid, lungs, kidney, PET/PET-CT (Positron Emission Tomography with Computed Tomography) and the remaining.

Due to the different characteristics between the practice of nuclear medicine and radiology in Portugal, it was decided to study both fields separately. So, the methodology to gather data includes three grounds:
• Compilation of data relative to nuclear medicine exams, analysis of the frequency of exams carried out in Portugal from 2013 to 2017 and attainment of specific data of ten patients for the DRL Portugal Project;
• Compilation of data relative to the TOP 20 radiodiagnostic exams and analysis of frequency of that exams carried out in Portugal from 2013 to 2017;
• Compilation of frequencies and determination of collective effective dose due to NM exams and TOP 20 exams.

The methodology followed in this work is summarized in the Table 1.

Table 1 – Used Methodology Diagram

<table>
<thead>
<tr>
<th>Data</th>
<th>Nuclear Medicine</th>
<th>Radiodiagnostic – TOP 20</th>
<th>Collective Effective Dose</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exam frequency and average activity per exam</td>
<td>Exam frequency</td>
<td>Direct data from NM</td>
</tr>
<tr>
<td></td>
<td>Survey sent to 38 NM centers (15 answers)</td>
<td>Regional Health Administration refund codes</td>
<td>Mean effective dose per exam for TOP 20 exams (DDM2)</td>
</tr>
<tr>
<td></td>
<td>• Data from 10 patients exams – DRL Portugal Project</td>
<td>+ Data from Portuguese Cardiovascular Intervention Association (APIC)</td>
<td></td>
</tr>
</tbody>
</table>

Nuclear Medicine

In order to collect data from all nuclear medicine centers in Portugal, it was carried out a list of all the institutions with a license from DGS, the responsible entity for the emission of radiological field licenses. According to the most updated list (May 2018), there are thirty eight nuclear medicine centers in Portugal [9]. Those centers are divided in 6 geographical regions:

1) Greater Lisbon: 17 centers, from which 6 participated, 4 declined the participation, and the remaining did not answer;
2) Greater Oporto and Northern Region: 10 centers, from which 5 participated and 5 did not answer;
3) Center Region: 6 centers, from which 3 participated, 2 did not answer and 1 is not statistically significant;
4) Algarve Region: 1 center that did not answer;
5) Madeira: 2 centers, from which 1 participated and 1 declined the participation;
6) Azores: 2 centers, that for being too recent did not provide enough data for this study.
So, from a total of 38 centers of NM in Portugal: 15 provided data for this study (39,5%), 2 centers are too recent and do not have enough data to be included in this study (5,3%), 5 declined to participate (13,2%), 1 is an education institution (2,6%), 1 is not statistically significant (2,6%) and 14 did not answer (36,8%).

To determine collective effective dose for nuclear medicine exams, it is necessary to define the quantities that allows to establish a methodology. From the value of the average injected activity for each exam and the frequency (data provides from the centers), it is possible to determine:

- Weighted average activity for each nuclear medicine procedure, $A_{avg}(x)$, determined by the following expression:

$$A_{avg}(x) = \frac{\sum_{i=1}^{n} A_i \cdot freq_i(x)}{\sum_{i=1}^{n} freq_i(x)} \quad \text{(Equation 1)}$$

In which $n$ is the total number of NM centers that participated in this study (in this case, 15 centers), $A_i$ is the average activity reported by the nuclear medicine center $i$ for the procedure $x$, and $freq_i(x)$ represents the annual frequency of each procedure $x$ in the center $i$;

- Per caput dose for each procedure of nuclear medicine:

$$\frac{D}{\text{caput}}(x) = \frac{A_{avg}(x) \cdot e_x \cdot \sum_{i=1}^{n} freq_i(x)}{\text{poruguese population}} \quad \text{(Equation 2)}$$

In which $e_x$ is the conversion coefficient of activity in effective dose (mSv/MBq) that depends on the radiopharmaceutical used in the procedure $x$ [7,10-12]. Data referring to Portuguese population are withdrawn from [13], and for 2017, the Portuguese population corresponds to 10572721 individuals;

- Total per caput dose due to all NM corresponds to the sum of per caput dose obtained for each procedure $x$.

As not all centers answered, and because the response rate was 39,5%, it was decided to make a linear extrapolation of the data, using an extrapolation factor of $1/0.395=2.53$. Uncertainty over estimated dose per type of NM exam was determined from weighted average standard deviation of the obtained activities.

In the scope of DRL Portugal Project, it was required data related to ten specific exams from patients with height ranging from 160 centimeters to 180 centimeters and weight ranging from 60 kg to 80 kg. For these ten exams (two cardiac, two renal, two bone, two thyroid and two PET-CT), it was required the patient’s genre, administered radiopharmaceutical and administered activity with the purpose of delivering the obtained data to the project managers in order to calculate DRL of the NM exams in Portugal.

**Radiodiagnostic**

Due to time constraint and in order to compile the frequencies of the TOP 20 radiodiagnostic exams in useful time, only five Regional Health Administrations (RHA) were contacted (North, Center,
Lisbon, Alentejo and Algarve) in order to provide exam frequency carried out in the agreed regimen. From all RHA contacted, four (all except Alentejo), provided the necessary data to evaluate the Portuguese population exposure due to radiodiagnostic exams. APIC provided data related to coronary angioplasty exams, from which it was made an extrapolation for the cardiac angiographies.

To determine the collective effective dose for the radiodiagnostic exams, the following methodology was considered:

- Determination of average effective dose per exam - this dose can be calculated through measurements in radiology rooms or through data of average dose acquired from academic works, published studies, etc. In this work, the effective dose per exam values used and their uncertainties are those published in the Dose Datamed II Portugal document [4];
- Determination of collective dose – For this, it was required to the RHA the frequency of each exam in Portugal. This allows to estimate the frequency of this exams in the country;
- Average annual *per caput* dose for each TOP 20 exam is calculated from the ratio between annual average collective effective dose per type of exam and the total Portuguese population [13];
- Total average per caput annual dose is obtained adding up average per caput annual doses of all the exams.

**Results**

**Frequency estimation and collective effective dose due to Nuclear Medicine exams**

Presented data for nuclear medicine contemplates data from 2010 until 2017. Data from 2010 to 2012 come from previously developed work, using the same methodology [4,5,7] and data from 2013 to 2017 were obtained recently for the development of this work.

In Figure 1 is represented a graphic where is possible to observe time evolution of the NM exams considered.

![Figure 1. Total annual frequencies of the seven different groups of NM exams.](image-url)
Besides annual frequencies of different NM exams, it was also calculated the total collective effective dose (in manSv) and per caput dose (mSv/caput). Data are shown in Table 2.

Table 2. Collective effective dose due to total NM exams, per caput dose and uncertainties between the years of 2010 and 2017.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total collective effective dose (manSv)</th>
<th>Portuguese Population [13]</th>
<th>Per caput effective dose (mSv/caput)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010*</td>
<td>840,3</td>
<td>10 572 721</td>
<td>0,080</td>
</tr>
<tr>
<td>2011*</td>
<td>625,64±41,64</td>
<td>10 542 398</td>
<td>0,059±0,004</td>
</tr>
<tr>
<td>2012*</td>
<td>565,07±57,31</td>
<td>10 487 289</td>
<td>0,054±0,005</td>
</tr>
<tr>
<td>2013</td>
<td>921,12±10,68</td>
<td>10 427 301</td>
<td>0,088±0,001</td>
</tr>
<tr>
<td>2014</td>
<td>911,51±12,30</td>
<td>10 374 822</td>
<td>0,088±0,001</td>
</tr>
<tr>
<td>2015</td>
<td>885,19±11,81</td>
<td>10 341 330</td>
<td>0,086±0,001</td>
</tr>
<tr>
<td>2016</td>
<td>912,39±15,58</td>
<td>10 309 573</td>
<td>0,088±0,002</td>
</tr>
<tr>
<td>2017</td>
<td>923,45±16,90</td>
<td>10 291 027</td>
<td>0,090±0,002</td>
</tr>
</tbody>
</table>

*Data relative from 2010 to 2012 were obtained from [5,7].

**Frequencies estimation and annual effective collective dose for TOP 20 radiodiagnostic exams**

Frequencies distribution of TOP 20 exams, divided in radiographies, fluoroscopy exams, computed tomography and intervention for the years 2010 and 2013 to 2017 are represented in Figure 2.

Figure 2. Annual frequencies of different TOP 20 radiodiagnostic exams carried out in 2010 and from 2013 to 2017.
From the results relative to frequency of radiodiagnostic exams, both, total collective effective dose (in manSv) and per caput dose (mSv/caput), were calculated (see Table 3).

Table 3. Total collective effective dose due to the total radiodiagnostic exams carried out and respective per caput dose and uncertainties for the years 2010 and from 2013 to 2017.

<table>
<thead>
<tr>
<th>Year</th>
<th>Total collective effective dose (TOP 20) (manSv)</th>
<th>Total collective effective dose (manSv)</th>
<th>Per caput effective dose (mSv/caput)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010*</td>
<td>10164.44 ± 7148.06</td>
<td>10164.44 ± 7148.06</td>
<td>0.96 ± 0.68</td>
</tr>
<tr>
<td>2013</td>
<td>5748.94 ± 3679.20</td>
<td>8212.77 ± 5256.00</td>
<td>0.79 ± 0.50</td>
</tr>
<tr>
<td>2014</td>
<td>6016.18 ±3836.82</td>
<td>8594.54 ± 5481.17</td>
<td>0.83 ± 0.53</td>
</tr>
<tr>
<td>2015</td>
<td>6226.61 ± 3953.58</td>
<td>8895.16 ± 5647.97</td>
<td>0.86 ± 0.54</td>
</tr>
<tr>
<td>2016</td>
<td>6240.51 ± 3968.00</td>
<td>8915.01 ± 5668.57</td>
<td>0.87 ± 0.54</td>
</tr>
<tr>
<td>2017</td>
<td>6547.07 ± 4145.48</td>
<td>9352.96 ± 5922.11</td>
<td>0.91 ± 0.57</td>
</tr>
</tbody>
</table>

*Data from 2010 obtained from [4].

Comparison with other countries

Analyzing and comparing the results obtained in this work for the NM exams to previous studies, namely DDM2 [4], it is verified that since 2010 Portugal presents a lower relative frequency of bone imaging comparing to the average frequency of other European Union (EU) countries. While bone imaging corresponds to almost 40% of NM exams in EU, in Portugal it corresponds to about 25% [7, 14]. Considering the cardiac exams, these hold a high prevalence and they contribute the most to collective dose in population, as verified in DDM2.

Relatively to average effective per caput dose in Portugal for NM exams (Table 2), it showed higher values than the existing values for the average in EU countries. Therefore, average effective dose per caput reported in DDM2 is 0.054 mSv per caput and, in this work, the values obtained varied from 0.086 mSv per caput in 2015 and 0.090 mSv per caput in 2017.

For radiodiagnostic exams in Portugal, similar to other EU countries, CT exams are the ones that contribute the most to collective effective dose in population [14]. Regarding to average per caput effective dose in Portugal (Table 3), the values obtained in this work are lower than the existing values for the average of EU countries (1.06 mSv per caput) [14, 15], and similar to obtained values for average effective dose in Slovenia (0.6 mSv per caput) [16].
Conclusions

Owing to the raising access to healthcare and fast evolution of health related technologies, population has been increasingly exposed to ionizing radiation due to medical exams. Because of this, it is mandatory to carry out periodical studies to evaluate the population exposure in the medical scope. In this context, this study presents an estimation of the Portuguese population dose exposure due to radiodiagnostic and nuclear medicine exams.

Analyzing previous published data of annual frequencies on NM exams carried out in Portugal, between 2010 and 2012, it was verified a decrease in the frequency of performed exams. This work is focused on the data collected from 2013, and from that year on, it is shown an increasing number in performed NM exams, mainly PET/PET-CT exams. For all the considered years, it was verified that cardiac exams have the most annual frequency, followed by bone exams and PET/PET-CT. It also shows that myocardium perfusion with thallium exam stopped being performed in 2015. Per caput dose, as occurred with annual frequencies of the carried out exams and total collective effective dose, decreased between 2010 and 2012 presenting a value of 0.054 ± 0.011 mSv per caput. It is important to emphasize, however, that the data collected between 2010 and 2012 had different response rates, of about 80%. In what concerns the contribution per NM exam group for the total collective dose, cardiac exams were the ones which presented the highest dose percentage throughout those years (40% to 55%), followed by bone exams (20% to 28%) and PET/PET-CT exams (15% to 23%).

In what concerns the compilation of necessary data to evaluate Portuguese population exposure due to radiodiagnostic exams, due to time constraint, only the contacted RHAs provided necessary data, having obtained those data from four out of five RHAs (Algarve, Center, Lisbon and North). Data referring to Alentejo were estimated from Lisbon data, considering population ratios in both regions. Because of the lack of response from ADSE (Assistance in Disease to Civil Servants of the State), the data were also estimated from the total data of the RHAs, considering that it corresponds to 10% of the total value of the exams [4]. Values for coronary angioplasty exams were obtained through APIC [17]. Across these data, and using the ratio between cardiac angiography and coronary angioplasty exams acquired in 2010 [4], the exam frequencies of cardiac angiographies were estimated for the period from 2013 to 2017. The estimate of final frequencies was extrapolated in order to consider carried out exams in general regimen, using also the ratio obtained in 2010 [4]. Dose values per exam were the ones considered in the previous work [4,5].

Analyzing annual frequencies of radiodiagnostic exams performed in Portugal, it was verified that between the data previously gathered in 2010 [4], and data obtained from 2013 to 2017 (this work) it was observed a depletion in total exams performed. However, due to time constraints and the fact that there were no hospital surveys carried out like the previous study [4], these data are not directly comparable. Between 2013 and 2015 the number of radiodiagnostic exams performed has increased in Portugal. According to the acquired data, the most common performed radiodiagnostic procedures are radiographies, and among them, thorax is the most frequent one.

Relatively to the contribution of the contemplated radiodiagnostic data for collective dose, CT exams are the ones that contribute the most, from 64% to 70% of the total collective dose from 2013
to 2017. With regards to total collective effective dose and per caput dose, both have increased since 2013, being that in 2017 per caput dose value was 0.91 ± 0.57 mSv per caput.

This study, against to previously studies, presents the advantage that the results count on the uncertainty analysis in annual frequencies and collective effective dose, which allows to estimate more accurately the obtained data, something that was not done in 2010.

**Recommendation for professionals and health institutions**

Considering the results obtained, the main recommendation, due to legal obligation and national public health interest, would be to impose periodic studies to evaluate the exposure to ionizing radiation, on behalf of health authorities. For such purpose, it could be created a consortium with all the organisms and institutions that have interest in these periodical evaluations, as: the RHAs, ADSE, DGS and Instituto Superior Técnico. This consortium would be responsible for the periodic evaluation of total collective effective dose in Portuguese population due to medical activities, which would encompass the execution of a project with national interest that would include the disclosure of the acquired data to all national institutions, as well as data collection and processing. For this purpose, for example, a platform could be created so that the data (such as the ones required for this study) could be periodically and automatically registered, with the main goal to provide important data to decision making in the health field. It would also be the consortium’s responsibility to disclose the acquired data, sensitization and communication to the public and health professionals, in order to make awareness for the importance of using ionizing radiation in a safe and optimized way.

**References**


