Effective radiation dose of three diagnostic tests in cardiology: Single photon emission computed tomography, invasive coronary angiography and cardiac computed tomography angiography

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KEYWORDS
Ionizing radiation; Single photon emission computed tomography; Invasive coronary angiography; Cardiac computed tomography; Obesity

Abstract
Introduction: Diagnostic tests that use ionizing radiation play a central role in cardiology and their use has grown in recent years, leading to increasing concerns about their potential stochastic effects.

The aims of this study were to compare the radiation dose of three diagnostic tests: single photon emission computed tomography (SPECT), invasive coronary angiography (ICA) and cardiac computed tomography (cardiac CT) and their evolution over time, and to assess the influence of body mass index on radiation dose.

Methods: We assessed consecutive patients included in three prospective registries (SPECT, ICA and cardiac CT) over a period of two years. Radiation dose was converted to mSv and compared between the three registries. Differences over time were evaluated by comparing the first with the fourth semester.

Results: A total of 6196 exams were evaluated: 35% SPECT, 53% ICA and 22% cardiac CT. Mean radiation dose was 10.7±1.2 mSv for SPECT, 8.1±6.4 mSv for ICA, and 5.4±3.8 mSv for cardiac CT (p<0.001 for all). With regard to the radiation dose over time, there was a very small
Conclusions: Cardiac CT had a lower mean effective radiation dose than invasive coronary angiography, which in turn had a lower mean effective dose than SPECT.

There was a significant increase in radiation doses in the ICA registry and a significant decrease in the cardiac CT registry over time.

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Dose efetiva de radiação de três exames de diagnóstico em cardiologia: cintigrafia de perfusão miocárdica, coronariografia invasiva e tomografia computorizada cardíaca

Resumo
Introdução: Os exames diagnósticos que usam radiação ionizante têm um papel central na cardiologia e a par do seu uso crescente, tem aumentado a preocupação pelos seus potenciais efeitos estocásticos.

Os objetivos deste estudo foram: 1) Comparar a dose de radiação de três exames: Cintigrafia de perfusão miocárdica (SPECT), coronariografia invasiva (CAT) e tomografia computorizada cardíaca (AngioTC) e a sua evolução temporal. 2) Avaliar o impacto do índice de massa corporal na dose de radiação.

Métodos: Doentes consecutivos incluídos em três registos prospectivos (SPECT, CAT e AngioTC) durante dois anos. A dose de radiação foi convertida a mSv e comparada entre os três registos. A evolucão temporal foi avaliada por comparação do 1.º e 4.º semestres.

Resultados: Foram avaliados 6196 exames: 35% SPECT, 53% CAT e 22% AngioTC. A dose de radiação foi: 10,7 ± 1,2 mSv para o SPECT; 8,1 ± 6,4 mSv para o CAT; 5,4 ± 3,8 mSv para a AngioTC (p < 0,001 todas comparações).

Evolução temporal da dose de radiação: redução muito ligeira no SPECT (10,7 para 10,5 mSv; p = 0,004); aumento significativo (25%) no CAT (7,0 para 8,8 mSv; p < 0,001); redução significativa (29%) na AngioTC (6,5 para 4,6 mSv; p < 0,001). A obesidade associou-se a níveis de radiação significativamente mais elevados nos três exames.

Conclusão: O exame associado a uma menor dose de radiação foi a AngioTC, seguida do CAT que, por sua vez, foi menor que a do SPECT. Houve um aumento significativo da dose de radiação no registo CAT e uma redução significativa no registo da AngioTC ao longo do tempo.

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List of abbreviations

BMI Body mass index
CAD coronary artery disease
CT computed tomography
ICA invasive coronary angiography
SPECT single photon emission computed tomography

Introduction

In recent years, the development of imaging techniques using ionizing radiation has resulted in considerable progress in the diagnosis and treatment of heart disease. Three commonly used diagnostic modalities that involve ionizing radiation are used for assessing patients with possible coronary artery disease (CAD): single photon emission computed tomography (SPECT), cardiac computed tomography (cardiac CT) and invasive coronary angiography (ICA), the latter being considered the gold standard for the diagnosis of CAD.

Different radiation doses have been reported for each of these exams, ranging from 5 to 10 mSv for ICA, 6 to 15 mSv for SPECT, and 4 to 21 mSv for cardiac CT.2–5 With more frequent use of these exams, there have been growing concerns about the radiation’s potential secondary effects, especially the stochastic effects of high cumulative doses over time.6,7

We have previously reported on the effective radiation dose associated with cardiac CT in a single-center registry, documenting a significant decrease in dose over time, and were able to identify the predictors of higher dose.8

New scanners and acquisition protocols have recently been developed which lead to significant reductions in radiation dose associated with cardiac CT.9,10

The aims of this study were to evaluate and compare the radiation dose used in three diagnostic tests – SPECT, ICA and cardiac CT – and their evolution over time, and to assess the influence of body mass index on radiation dose.
Methods

From three prospective registries of SPECT, ICA and cardiac CT, we selected for this analysis the exams performed during a two-year period (October 1, 2008 to September 30, 2010) in which the indication was assessment of possible CAD.

The exams were performed with an SMV DST-XL gamma camera using 99m Tc-tetrofosmin with stress/rest or rest/stress protocols (SPECT registry), a Siemens Coroskop TOP/ARTIS dFC system (ICA registry), and a Siemens Somatom Definition dual-source scanner (cardiac CT registry). The effective radiation dose was converted to mSv in accordance with current literature and the manufacturer’s product information and compared between the registries. Briefly, a factor of 0.014 mSv/Gy cm was used for the conversion of cardiac CT dose-length product,9,11 a factor of 0.183 mSv/Gy cm² was used for the conversion of ICA dose-area product,12,13 and factors of 0.0060 mSv/MBq⁻¹ (after exercise) and 0.0071 mSv/MBq⁻¹ (at rest) were used for the conversion of injected activity in SPECT.14-16 To evaluate the evolution of radiation doses over time, the study period was divided into four semesters according to the date of the exam and effective radiation dose was compared between the first and last semesters in each registry. All prospectively collected variables in the respective registries were analyzed, looking for predictors of dose change over time.

Statistical analysis

Continuous variables are presented as mean ± standard deviation (unless otherwise specified), and categorical variables as number (n) or frequency (%).

Continuous variables were analyzed using the Mann–Whitney or Kruskal–Wallis nonparametric tests. The chi-square test was used to assess differences in frequencies.

Statistical significance was accepted for two-sided p values <0.05.

The statistical analysis was performed using SPSS Statistics 17.0 for Windows.

Results

During the two-year period of this analysis, 6196 exams were performed: 3267 (52.7%) ICA, 1585 (25.6%) SPECT and 1344 (21.7%) cardiac CT. The demographic and clinical characteristics of the study population are presented in Table 1.

Mean effective radiation dose was 8.2±5.6 mSv for the whole population, 10.7±1.2 mSv for SPECT, 8.1±6.4 mSv for ICA and 5.4±3.8 mSv for cardiac CT (p<0.001 for all comparisons, Figure 1).

Division of the study period into semesters showed that there was a small but significant reduction in mean effective radiation dose over time for SPECT (10.7 to 10.5 mSv; p<0.01). In cardiac CT there was a significant 29% decrease in mean effective radiation dose (6.5 to 4.6 mSv, p<0.001) and in ICA a significant 25% increase (7.0 to 8.8 mSv; p<0.001) (Table 2 and Figure 2).

The factors associated with the 25% increase in mean effective radiation dose with ICA from the first to the fourth semester were the higher proportions of positive exams, radial vascular access and exams performed by fellows in

Table 1 Demographic and clinical characteristics of the study population.

<p>| Table 1 | Demographic and clinical characteristics of the study population. |</p>
<table>
<thead>
<tr>
<th>Cardiac CT (n=1344)</th>
<th>ICA (n=3267)</th>
<th>SPECT (n=1585)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years, mean ± SD)</td>
<td>59±12</td>
<td>66±12</td>
</tr>
<tr>
<td>Male (%)</td>
<td>60%</td>
<td>61%</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>27.3±4.3</td>
<td>27.3±4.3</td>
</tr>
<tr>
<td>Diabetes (%)</td>
<td>16%</td>
<td>29%</td>
</tr>
<tr>
<td>Hypertension (%)</td>
<td>57%</td>
<td>72%</td>
</tr>
<tr>
<td>Dyslipidemia (%)</td>
<td>54%</td>
<td>57%</td>
</tr>
<tr>
<td>Smoking (%)</td>
<td>27%</td>
<td>31%</td>
</tr>
<tr>
<td>Previous MI (%)</td>
<td>3%</td>
<td>17%</td>
</tr>
<tr>
<td>Previous PCI (%)</td>
<td>7%</td>
<td>18%</td>
</tr>
<tr>
<td>Previous CABG (%)</td>
<td>3%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Values are means (SD) or percentages. BMI: body mass index; CABG: coronary artery bypass grafting; CT: computed tomography; ICA: invasive coronary angiography; MI: myocardial infarction; N/A: not available; PCI: percutaneous coronary intervention; SPECT: single photon emission computed tomography.

Figure 1 Mean effective radiation dose used in each exam studied. CT: computed tomography; ICA: invasive coronary angiography; SPECT: single photon emission computed tomography.
Table 2  Mean effective radiation dose for each exam over the four semesters.

<table>
<thead>
<tr>
<th></th>
<th>1st semester</th>
<th>2nd semester</th>
<th>3rd semester</th>
<th>4th semester</th>
<th>p (1st vs. 4th)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECT</td>
<td>10.7 ± 1.1</td>
<td>10.7 ± 1.4</td>
<td>10.7 ± 1.3</td>
<td>10.5 ± 0.9</td>
<td>0.004</td>
</tr>
<tr>
<td>ICA</td>
<td>7.0 ± 6.0</td>
<td>7.6 ± 5.6</td>
<td>9.0 ± 6.9</td>
<td>8.7 ± 6.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cardiac CT</td>
<td>6.5 ± 3.7</td>
<td>6.2 ± 4.2</td>
<td>5.0 ± 4.1</td>
<td>4.6 ± 3.0</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

CT: computed tomography; ICA: invasive coronary angiography; SPECT: single photon emission computed tomography.

Table 3  Variables associated with increase in ICA radiation dose and decrease in cardiac CT radiation dose.

<table>
<thead>
<tr>
<th></th>
<th>ΔmSv</th>
<th>1st semester</th>
<th>4th semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proportion of patients undergoing PCI</td>
<td>ND</td>
<td>39%</td>
<td>42%</td>
</tr>
<tr>
<td>Exams performed by fellows in training</td>
<td>↑29%</td>
<td>26%</td>
<td>52%</td>
</tr>
<tr>
<td>Proportion of radial vascular access</td>
<td>↑15%</td>
<td>1%</td>
<td>46%</td>
</tr>
<tr>
<td>Cardiac CT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prospective acquisition</td>
<td>↓60%</td>
<td>0%</td>
<td>45%</td>
</tr>
</tbody>
</table>

CT: computed tomography; ICA: invasive coronary angiography.

Figure 2  Time trends in mean effective radiation dose used in each exam. CT: computed tomography; ICA: invasive coronary angiography; SPECT: single photon emission computed tomography.

Figure 3  Mean effective radiation doses for each exam and different body mass index classes. BMI: body mass index; CT: computed tomography; ICA: invasive coronary angiography; SPECT: single photon emission computed tomography.

The only variable associated with the decrease in effective radiation dose for cardiac CT was the use of prospective (step-and-shoot) acquisition: the use of a prospective acquisition protocol was associated with a decrease of 60% in effective radiation dose. In the first semester no exams were performed with this protocol, while in the fourth semester 45% were acquired prospectively (Table 3).

The influence of body mass index on mean effective radiation dose was also evaluated. There was a significantly higher dose in obese patients (BMI ≥30 kg/m²) compared to overweight patients, which in turn was higher that in patients with normal weight (BMI <25 kg/m²) (Figure 3).

Discussion

In this analysis, we found significantly different effective radiation doses associated with common diagnostic tests used in cardiology. The dose was highest for SPECT, followed by ICA and lowest for cardiac CT. Furthermore, we found
Effective radiation dose of three diagnostic tests in cardiology

985

some time trends in the mean effective radiation dose asso-
ciated with ICA and cardiac CT related to particular clinical
and procedural methodologies.

The biological effects of ionizing radiation are related
to the cumulative effective dose, and doses above 100 mSv
have been linked to stochastic effects including the develop-
ment of cancer, while the effects of lower radiation levels,
common in diagnostic X-ray imaging, are much less clear.4,17
Although other theoretical models based on dose-threshold
and hormetic effects have been proposed, the more con-
servative linear no-threshold model, which assumes that no
level of radiation is without risk, is widely accepted.4,17

On this basis, procedures that use ionizing radiation
should be performed in accordance with the "as low as
reasonably achievable" philosophy, and physicians ordering
and performing cardiac imaging diagnostic tests should be
familiar with the associated radiation doses and with ways
in which they can be minimized.

The mean effective radiation dose we found for each
exam is in agreement with previous studies.2,4,6,18 Furth-
ernmore, we confirmed that certain variables influence the
effective radiation dose delivered by these exams. For ICA,
the effective radiation dose increased with the use of radial
access and with less experienced operators, which is in line
with published data.13,19 The higher radiation dose in the
ICA registry over time was also associated with a higher
proportion of positive exams; although we did not quanti-
fy the difference between positive and negative ICA, we
can assume that positive tests needed more cine angiograms
of the coronary arteries, with a consequent increase in the
radiation dose used.

For cardiac CT, the introduction and increasingly fre-
cquent use of a prospective protocol during the study period
was associated in our experience with a significant decrease
in the effective radiation dose for this exam, as has been
demonstrated by other authors.10-22 Finally, for SPECT, the
dose change over time was very small, which is to be
expected since there were no changes in protocol during the
study period.

It is worth noting that during the same period, doses asso-
ciated with stress-only and rest-only SPECT studies were
significantly lower (with mean effective doses of 2.3±0.9
mSv and 5.8±1.0 mSv, respectively) but they were not con-
sidered for the purpose of this study, and the small number
of patients involved (n=49 and n=63, respectively) would not
have had a significant impact on the overall SPECT radiation
dose.

Mean effective radiation doses were significantly higher
for obese patients in all the exams analyzed. This was espe-
cially true for cardiac CT and ICA, with an almost two-fold
increase in radiation dose compared to their normal-weight
counterparts. In the SPECT registry, the effect of BMI was
less pronounced. This should be taken in consideration when
selecting the appropriate diagnostic exam, especially for
those at higher risk from radiation exposure, like women
and younger patients.23 In line with this, particular atten-

Conclusions

In these registries of diagnostic tests commonly used in car-
diology, the mean effective radiation dose used in cardiac
CT was lower than that used in ICA, which in turn was
lower than the doses used in SPECT. There was a signifi-
cant increase over time in the mean effective radiation dose
associated with ICA, mainly related to the increased use of
radial access, and a decrease in cardiac CT doses as a con-
sequence of the implementation of a prospective protocol.
Obesity was associated with a significantly higher radiation
dose in all three exams.

Ethical disclosures

Protection of human and animal subjects. The authors
declare that the procedures followed were in accordance
with the regulations of the relevant clinical research ethics
committee and with those of the Code of Ethics of the World
Medical Association (Declaration of Helsinki).

Confidentiality of data. The authors declare that they have
followed the protocols of their work center on the publica-
tion of patient data and that all the patients included in the
study received sufficient information and gave their written
informed consent to participate in the study.

Right to privacy and informed consent. The authors have
obtained the written informed consent of the patients or
subjects mentioned in the article. The corresponding author
is in possession of this document.

Conflicts of interest

The authors have no conflicts of interest to declare.

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