Updated effective doses in radiology

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Abstract
The aim of this study was to review recent literature in order to provide updated values of the typical effective doses associated with the top 20 imaging tests for adults and children and for the most widely used set of weights (ICRP60) as well as for the most recent one (ICRP103). We performed a systematic research on radiation dosimetry in radiology published from 2007 onwards through the Medline, Embase and Cochrane Library Plus databases. We also included studies backed by scientific or governmental organizations. Other variables included: year and type of study (survey or descriptive), country, method and sample used for the measurement. Mean effective dose, minimum, maximum and standard deviation were calculated. We compared our results with previous evidence and with data from DDM2. We included 27 articles and 5 web references in the study. A total of 378 values from the 20 procedures included were obtained, 280 (74%) using ICRP60 and 98 (26%) using ICRP103.

Effective doses for CT procedures in children were very similar to those for adults, with the exception of CT Trunk, but fluoroscopy procedures had consistently lower dose. There were differences between the current data with either ICRP60 or ICRP103, and the previous published data. In conclusion, we provided the best available evidence from literature to evaluate the effective dose received by each patient for the most typical examinations. According to the recommendations from the Report 154 and from the European Council Directive, these results could also be useful to estimate the range of average exposures to the population.
Keywords: radiation, imaging test, exposure

(Some figures may appear in colour only in the online journal)

1. Introduction

In 2013 the European Council published the new Basic Safety Standards Directive regarding ionizing radiation [1]. The directive introduced several requirements for medical exposures and the associated doses, for example, providing the patient with adequate information relating to the benefits and risks associated with the radiation dose prior to the medical exposure, and taking into account radiation doses in referral guidelines. The evidence shows that clinicians nowadays lack awareness of the doses associated with the imaging tests they prescribe [2].

One of the different quantities used in radiological protection that could potentially fulfill at least part of those requirements is the effective dose. The international commission for radiological protection (ICRP) in its Publication 103 [3] warns that the effective dose should not be used for investigations of individual exposure and risk. But since it condenses in a single value the total detriment to the patient when the exposure has not been homogeneous (i.e. some organs were exposed while others were not), the effective dose holds a central position in the current system of radiological protection as the magnitude that allows comparisons between very different exposures, techniques and technologies, and thus, enables clinicians to discuss the risks and benefits of imaging tests with patients.

Increasing the knowledge of the typical effective dose of a certain procedure is, therefore, a basic starting point when communicating the risk that an imaging test implies with a patient and also to help clinicians understand it.

The most recent review of the available evidence to identify the effective dose associated with each radiodiagnostic procedure was published in 2008 by Mettler et al [4]. They analyzed more than 150 peer-reviewed articles published between 1980 and 2007, which were included in a catalogue of estimated effective doses for a large number of common imaging tests. However, although this review is an essential reference, there was no specific mention of pediatric doses and the methodology to calculate each effective dose is not specified and, therefore, not reproducible. Moreover, it was developed before the updating of the ICRP Publication in 2007 and it does not include relevant initiatives, such as data from the dosedatamed project.

In 2004, the European Commission launched an international survey on collective effective doses from medical x-ray procedures, known as dosedatamed (DDM), which included 10 European countries with previous experience conducting surveys measuring the collective effective dose [5]. The project selected a set of 20 imaging tests that were among the highest contributors to the collective effective dose (‘the top 20’). This project was updated with the dosedatamed2 (DDM2) that included 36 European countries [6]. In DDM2 the information from each country is based on national surveys that follow Report 154 of the European Commission [7], a protocol built on the experience from DDM1. Report 154 establishes that, if patient dose measurements are not available for a given country, data should be taken either from literature that matches as closely as possible the healthcare setting of the country or from the data provided by the DDM surveys.

Understanding the typical effective doses of the different imaging procedures performed at a hospital is a necessary step towards optimization and patient-risk minimization. Referral guidelines and protocols for communicating the risk-benefit balance to the patients could also benefit from updated information about effective doses. In light of all this, we reviewed recent literature in order to provide updated values of the typical effective doses associated with the top 20 imaging tests for adults and children and for the most widely used set of weights (ICRP60 [8]) as well as for the most recent one (ICRP103).
2. Material and methods

2.1. Search strategy and eligibility criteria

We searched the scientific literature on radiation dosimetry in radiology (selecting the top 20 tests defined by DDM project) published from 2007 onwards. The MEDLINE, EMBASE and Cochrane Library Plus databases were searched by using exploded headings under the following MesH terms: ‘Radiation, Ionizing’ (Mesh) OR ‘Radiation Monitoring’ (Mesh) OR ‘Radiation Dosage’ (Mesh) AND ‘X-Rays’ (Mesh). We limited the studies to those evaluating humans and language was restricted to English or Spanish.

We also included studies backed by governments and/or scientific societies published or updated since 2007, such as the national surveys performed as part of the DDM2 project or the nationwide evaluation of x-ray trends (NEXT) of the US Food and Drug Administration.

2.2. Study selection

We completed the search and performed the initial selection on the basis of abstracts and titles and in case of doubt the full article was reviewed. Only those studies that calculated the effective dose for at least one procedure were included. Inclusion was assessed by one reviewer and checked by a second reviewer. Any disagreement was resolved by consensus.

2.3. Data extraction

Reported values and ranges of effective dose were gathered for the top 20 procedures defined in DDM for both adults and children. We presented separately the data according to the ICRP weight used (ICRP 60 or ICRP 103) and divided the data into the four age groups recommended by DDM2 (<1, 1–5, 6–10 and 11–15 years old and adults). These age groups were created synthetically using the data in each article in those cases where there was not a direct correspondence.

We also extracted the following data: year of study, country, type of study (classified as: (a) surveys, including studies with a fully detailed and standardized sampling procedure in order to reduce the possibility of bias in order to calculate population doses, and (b) descriptive studies, in which the selection criteria and sampling procedure were not fully described or standardized. In the descriptive studies the aim is not to calculate population doses but to evaluate the doses of a small set of carefully selected patients and exposure parameters), type of sample (age (adult or pediatric 0–15 years old) and sex), method used for the measurement of effective dose, sample used for calculation (the actual number of individual patients or examinations averaged), ICRP weights, and radiodiagnostic procedure.

Two authors independently checked twice all of the extracted data against the publications, to ensure correct and complete data extraction. Countries were classified according to their gross domestic product (GDP) per capita. The GDP per capita of the European Union was used as the reference level and the rest of the countries were classified as ‘highly developed’ (above EU) or ‘not highly developed’ (below EU).

There were several references in which two or more procedures in the same study could be associated with the same procedure of interest or age group. Below are some examples of how they were handled:

- Separate values for x-ray pelvis and x-ray hips correspond to a single procedure of interest, x-ray pelvis and hip.
- X-ray chest includes always a posterioranterior projection, and sometimes an additional lateral projection. The total effective dose per procedure was calculated taking into account the frequency of lateral projections, when those values were available.
- For procedures like CT skull and CT brain, both correspond to CT Head. Thus, a weighted average was calculated if the frequency was available. Procedures of particular low frequency, e.g. CT nose were excluded.

2.4. Statistical analysis

The analyses were performed with Stata software package version 12 (Stata Corp, TX, USA). All tests were two sided and statistical significance was set at $p < 0.05$.

Using all extracted data, we calculated the mean effective dose for each procedure of interest using ICRP60 for all age groups and using ICRP103 for adults. The effective dose could not be calculated for pediatric patients using ICRP103 because there was a very limited amount of data available. Minimum, maximum, interquartile range and standard deviation were calculated when more than two values were available for an examination and a set of ICRP weights.

We assessed the relationship between several variables independently (sample size, type of study, country and year) with the mean effective dose through a linear regression with 95% CI. Finally, we compared our results with the review by Mettler et al and with data from DDM2.

3. Results

3.1. Description of the studies included

As figure 1 shows, the literature searches identified a total of 902 potentially relevant abstracts. Of these, 65 studies were retrieved for full test review and finally, 27 papers fulfilled the
Table 1. Description of the mean (minimum, maximum and standard deviation) effective dose (mSv) for the 20 selected examinations according to the two different sets of ICRP values used (ICRP60, from 1990, and ICRP103, from 2007) and the values of two references for comparison.

| Category               | Examination          | ICRP 60 | ICRP 103 | References for comparison |
|------------------------|----------------------|---------|----------|--------------------------|
|                        |                      | Mean    | Min-max  | Std dev                  |
|                        |                      | Mean    | Min-max  | Std dev                  |
|                        |                      | Mean    | Min-max  | Std dev                  |
|                        |                      | Mettler FA [5] | DDM2 [4] |
| Computed tomography    | CT abdomen           | 8.1     | 5.1-11.7 | 2.0                      | 6.8 | 5.6-8 | 1.2 | 8.0 | 11.3 |
|                        | CT chest             | 6.7     | 4.4-11.8 | 2.1                      | 7.0 | 4.6-10.1 | 1.7 | 7.0 | 6.6 |
|                        | CT head              | 1.8     | 1.4-2.6  | 0.4                      | 1.7 | 0.9-2.6 | 0.5 | 2.0 | 1.9 |
|                        | CT neck              | 3.2     | 1.8-6.0  | 1.3                      | 3.0 | 1.7-5.8 | 1.9 | 3.0 | 2.5 |
|                        | CT pelvis            | 8.3     | 4.0-11.9 | 2.4                      | 7.4 | 5.7-9.9 | 2.2 | 6.0 | 7.3 |
|                        | CT spine             | 10.3    | 4.0-16.7 | 5.3                      | 7.0 | 1-12    | 0.0 | 6.0 | 7.7 |
|                        | CT trunk             | 12.2    | 6.7-15.8 | 3.3                      | 12.3 | 10-16 | 2.0 | — | 14.8 |
| Interventional cardiology | PTCA                | 19.5    | 7.4-48.6 | 15.1                     | 7.2 | — | — | 15.0 | 15.2 |
| Plain radiography      | Abdomen              | 0.92    | 0.21-2.1 | 0.6                      | 0.5 | 0.14-0.75 | 0.25 | 0.7 | 0.9 |
|                        | Cervical spine       | 0.08    | 0.02-0.18 | 0.06                     | 0.05 | 0.01-0.11 | 0.05 | 0.20 | 0.19 |
|                        | Chest/thorax         | 0.07    | 0.01-0.14 | 0.04                     | 0.05 | 0.01-0.07 | 0.02 | 0.02 | 0.10 |
|                        | Lumbar spine incl. LSJ | 1.2   | 0.2-1.9  | 0.6                      | 0.80 | 0.2-1.5 | 0.70 | 1.5 | 1.2 |
|                        | Mammography          | 0.33    | 0.26-0.46 | 0.11                     | 0.64 | — | — | 0.40 | 0.27 |
|                        | Pelvis & hip         | 0.90    | 0.45-1.82 | 0.47                     | 0.37 | 0.09-0.66 | 0.24 | 0.60 | 0.71 |
|                        | Thoracic spine       | 0.60    | 0.23-1.22 | 0.43                     | 0.50 | 0.1-1.2 | 0.40 | 1.00 | 0.64 |
| Fluoroscopy            | Ba enema             | 5.8     | 3.0-8.25 | 2.4                      | 2.9 | 2.2-3.5 | 0.90 | 8.0 | 8.5 |
|                        | Ba follow            | 3.5     | 1.2-7.7  | 3.7                      | 1.3 | 1.2-1.3 | 0.10 | 5.0 | 7.3 |
|                        | Ba meal              | 3.6     | 1.5-4.93 | 1.5                      | 4.5 | — | — | 6.0 | 6.2 |
|                        | Cardiac angiography  | 9.3     | 3.3-22.3 | 6.4                      | 3.1 | — | — | 7.0 | 7.7 |
|                        | Intra-venous urogram | 3.5     | 2.3-6.5  | 2.0                      | 2.1 | — | — | 3.0 | 2.9 |

Note: Minimum, maximum and standard deviations are only shown when more than one value was found.
eligibility criteria [8–34]. Out of 27 articles included, 11 (41%) were published in European countries, 5 (18%) in Asian countries, 5 (18%) in USA/Canada, 3 (11%) in Australia, 2 (8%) in Africa and 1 (4%) in Brazil.

We also searched the web for potentially relevant studies backed by scientific organizations or national agencies. Of the five web references included in the study [35–38], 4 (80%) were based on European countries. Of the 33 sources (studies and web references), 17 (63%) were surveys. Moreover, 22 (67%) sources calculated values using ICRP 60; 7 (21%) using both ICRP 60 and ICRP 103 and 4 (12%) used ICRP 103.

The details of the 27 articles and 5 web references included are shown in Annex 1.

3.2. Description of the effective doses (mSv) for adults in the 20 selected examinations

A total of 378 values from the 20 procedures included were obtained, 280 (74%) using ICRP60 and 98 (26%) using ICRP103. Table 1 and figures 2–4 show the main results for adults using both sets weights.

The values of the effective doses calculated using ICRP103 weights were lower than those calculated using ICRP60 weights for almost all procedures. The only exception is mammography, but this is due to the increase in weighting factor of the breasts (which has more than doubled, from 0.05 in ICRP60 to 0.12 in ICRP103).
3.3. Evaluation of the effective doses (mSv) for children

Table 2 shows the mean effective doses of the main procedures for children. Differences between age groups and with adults vary greatly between examinations. Effective doses for CT procedures in children, like CT Chest or CT Abdomen, were very similar to those for adults, with the exception of CT Trunk, but fluoroscopy procedures had consistently lower doses and the results were mixed regarding plain radiography, some techniques resulted in the same dose (Thoracic spine) while others showed the greatest difference (Abdomen or Pelvis & Hip plain radiographies for children <1 and 1–5 years old).

3.4. Comparison between the effective dose evaluated in this study (according to ICRP 60 and ICRP 103) and those evaluated previously (Mettler et al and Project DoseDataMed2) (table 1)

There were differences between the current data with either ICRP60 or ICRP103, and the previous published data. Figures 2–4 show these results graphically using box-and-whiskers plots. We calculated minimum–maximum, median and interquartile range for all procedures using ICRP60 and for those procedures for which we had enough values using ICRP103. The figures present these values together with the average values and the values by Mettler et al and DDM2.

3.4.1. Computed tomography (figure 2). Overall, there were similar effective dose values according to the publication. However, effective doses evaluated using both sets of weights were higher than those published by Mettler et al for CT spine and CT pelvis. The effective...
doses using ICRP 60 were higher than those shown by the project DDM2 in CT spine. The effective doses using ICRP103 were higher than those shown in DDM2 in CT neck.

3.4.2. Interventional (figure 3). Current data using ICRP103 showed lower effective dose values than data measured in other publications.

3.4.3. Fluoroscopy (figure 3). Effective doses evaluated using ICRP60 were higher than those published by Mettler et al and project DoseDataMed2 for cardiac angiography and intravenous urogram. Current data using ICRP103 showed lower effective dose values for all the fluoroscopy procedures included than data presented in other publications.

3.4.4. Plain radiography (figure 4). Current data using ICRP103 showed lower effective dose values than data measured in other publications. However, for ICRP60 the procedures Abdomen and Pelvis & Hip had a higher effective dose than the values of Mettler FA and DDM2.

4. Discussion

In this review we showed two sets of effective doses assessed for adults (using ICRP 60 and ICRP 103 weights) and a set of doses for pediatric patients (using only ICRP 60 weights) that could be used to estimate population exposure doses in clinical practice and in referral guidelines to help physicians to understand the variations between different examination techniques.
Ideally, only effective doses using the weights from ICRP 103, published in 2007, should have been included in the final estimations. However, we have found that most authors still use effective doses calculated using the weights from ICRP60. While the ICRP argues that the new definition of the effective dose is compatible with the previous one in terms of risk assessment, the difference between the values for Mettler et al., DDM2 and our ICRP60 and ICRP103 values described in this publication cannot be attributed solely to the change in weights. If we restricted our search to publications including values for both sets of weights, we would have found a ~5% decrease in effective doses, but our complete analysis shows a ~30% decrease. A similar comparison was previously made [11], where authors find a ~14% decrease across CT procedures.

In our opinion, this difference cannot be attributed solely to the change in ICRP weights, and thus, we also analyzed other parameters of interest such as the economic resources of the countries where each investigation was performed, the number of patients involved in the measuring process or the year of publication. We have found that none of these affected the results in a statistically significant manner.

The difference must be, therefore, related to the implications of using newer ICRP recommendations, which is probably related with a more current knowledge of all aspects involved in the calculation of the effective dose, including technology and dose-optimization techniques.

In our analysis we also wanted to find out if large country-wide surveys with complex sampling techniques or involving many patients were different to small local descriptive investigations. Neither the sample size nor the type of study proved to be a source of significant differences. While this is reassuring, a word of advice is needed.

Effective doses are calculated using mathematical phantoms modeling a standard man and woman, and studies often use patients fitting that standard to avoid non-standard patients skewing the data [34] or simply take the exposure parameters before the exposition is made (i.e. from the protocol) and calculate what the effective dose would have been if the patient

| Table 2. Description of the mean effective dose (mSv) for pediatric patients, according to age group and the comparison with adult effective dose (according to ICRP 60). |
|-------------------------------|-------------------|-------------------|-------------------|-------------------|
| **Effective dose (mSv) children** | **<1 year old** | **1–5 years old** | **6–10 years old** | **11–15 years old** | **Effective dose (mSv) adults** |
| **Computed tomography** | **CT abdomen** | 7.9 | 7.9 | — | — | 8.1 |
| | **CT chest** | 3.9 | 2.8 | 4.2 | 6.8 | 6.7 |
| | **CT head** | 1.7 | 1.6 | 1.8 | 1.6 | 1.8 |
| | **CT pelvis** | 7.9 | 7.9 | — | — | 8.3 |
| | **CT trunk** | 3.9 | 3.0 | 5.6 | 8.3 | 12.2 |
| **Plain radiography** | **Abdomen** | 0.07 | 0.09 | 0.15 | 0.27 | 0.9 |
| | **Cervical spine** | 0.02 | 0.03 | 0.05 | 0.10 | 0.08 |
| | **Chest/thorax** | 0.05 | 0.05 | 0.05 | 0.06 | 0.07 |
| | **Lumbar spine incl. LSJ** | 0.4 | 0.5 | 0.6 | 0.8 | 1.2 |
| | **Pelvis & hip** | 0.08 | 0.10 | 0.15 | 0.21 | 0.90 |
| | **Thoracic spine** | 0.39 | 0.42 | 0.77 | 1.18 | 0.60 |
| **Fluoroscopy** | **Ba enema** | 2.3 | 2.3 | 2.3 | 2.3 | 5.8 |
| | **Ba follow** | 1.2 | 1.2 | 1.2 | 1.2 | 3.5 |
| | **Ba meal** | 0.7 | 0.6 | 0.9 | 1.0 | 3.6 |
| | **Intra-venous urogram** | 0.5 | 0.5 | 0.7 | 1.0 | 3.5 |
had been standard. While this may be a reasonable method to avoid population doses being skewed, it would lead to individual reported doses being skewed. In other words, the reason descriptive studies and country wide surveys show no difference may very well be that the number of actual measurements and the way they are conducted (a selected group of ‘standard’ patients) is very similar in both cases.

To our knowledge, this is the first study proposing a complete set of typical effective doses for children. For occupational exposures (ages 18–70) it may be adequate to ignore age dependencies. However, given than medical exposures are nowadays the biggest contributor to the collective effective dose, we cannot ignore pediatric examinations. There were few studies estimating effective doses for children using ICRP103; thus, we calculated these data only using those studies applying ICRP60.

We performed a systematic search on several databases, and controlled observer concordance in both the study inclusion and during the data extraction. Nevertheless, it is possible that some articles with valid data could have been missed.

5. Conclusions

We have compiled and analyzed values of effective doses for the 20 procedures that typically contribute the most to the collective effective dose, using two sets of recommendations (ICRP60 and ICRP103), and the age groups recommended for the DDM2 project. Our results can be used for the purposes of optimization, comparison, to help clinicians in their daily practice in referral guidelines and also in communicating the risk-benefit of the procedures to the patients.

It is important to keep in mind that the effective dose was designed to estimate population risks and not individual risks. Two individuals with a different kind of irradiation (e.g. a Cardiac angiography versus a Pelvis CT) could have the same effective dose and contribute the same amount to the ‘risk pool’ but they will show different risks associated with their exposure. To calculate individual risks, the ICRP recommends using the absorbed and/or the equivalent organ dose and the individual risk factors of the patient.

We found that effective doses reported using ICRP103 weights were systematically smaller than those using ICRP60 weights, a difference that cannot be attributed solely to the difference in the weights itself. Therefore, if an institution carries out a dose survey and wants to compare its data with the literature, it will need the ‘right’ effective doses. To the best of our knowledge, this is the first time any attempt has been made to create a complete list of effective doses using ICRP103 weights for the most common procedures.

In conclusion, with this review, we provided the best available evidence from literature to evaluate the effective dose received by each patient for the most typical examinations. According to the recommendations from the Report 154 and from the European Council Directive [1, 7], these result could also be useful to estimate average exposure population to radiation.

Even though effective doses per examination are lower now than they were some years ago, population doses have increased steadily, because the number of examinations, especially the high-dose ones like CT, have increased [38, 39]. The knowledge of the typical effective dose of an individual examination in only a part of the integral approach proposed by the ICRP in its latest set of recommendations for the protection of patients. Radiological protection officers, medical physicists and all other health professionals involved must be aware of all aspects and always try to minimize exposures as much as possible.
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Annex 1. Table including the characteristics of the 27 peer-reviewed articles and 5 online sources included in the study (2007–2013)

Explanation of each column:

- Reference: number of the reference in the bibliography of the main article
- Country: country where the study was conducted
- Year: year in which the study was published
- Type of study:
  - Survey: studies with a fully detailed and standardized sampling procedure in order to reduce the possibility of bias in order to calculate population doses.
  - Descriptive: studies in which the selection criteria and sampling procedure were not fully described or standardized, because the aim was not to calculate population dose but rather to evaluate doses in a set of carefully selected patients and exposure parameters.
- Sample: Total number of patients included in the study.
- Age: Adults, Pediatric patients of both
- Calculation Method:
  - Examination protocol: effective doses are calculated using the parameters that the equipment has pre-configured for each examination.
  - Equipment dosimetry: effective doses are calculated using dosimetry data (e.g. absorbed dose, dose area product, DLP...) reported by the equipment.
  - Equipment parameters: effective doses are calculated using the parameters used by the equipment for the individual patients. This is particularly relevant for equipment that uses automatic exposure compensation (AEC).
  - Measurements on the equipment: the same as the previous point (equipment dosimetry) but with data measured using external equipment.
  - Conversion Factor: effective doses where calculated using equipment dosimetry and a published conversion factor, specific to the imaging modality and/or the site
  - Following Report 154: Euratom Report 154 gives a detailed explanation on how to calculate the effective dose for each imaging modality, including appropriate number of samples, QA procedures that should be performed, etc…
- Calculation Sample: number of independent data points (e.g. patients, but also scanners or even technicians using the same equipment) used to calculate the effective dose of each examination.
- ICRP Weights: ICRP Report used for the calculation (either ICRP60 or ICRP103 or both).
- Included Procedures: type of procedures included in the study (RX, RX/Fluor, CT, Interventional or a combination of these
| Reference | Country     | Year | Type of study | Sample                                                                 | Age                  | Calculation method                                                                 | Calculation sample | ICRP weights | Included procedures |
|-----------|-------------|------|---------------|------------------------------------------------------------------------|----------------------|-------------------------------------------------------------------------------------|-------------------|--------------|--------------------|
| [8]       | France      | 2012 | Survey        | 27,362 examinations                                                    | Pediatric            | Examination protocol                                                              | 22 scanners       | 60           | CT                 |
| [9]       | Turkey      | 2008 | Descriptive   | 5 rooms in a single institution                                        | Adults               | Equipment dosimetry                                                               | 11-59             | 60           | Interventional     |
| [10]      | Australia   | 2012 | Survey        | 220 patients, Aosta valley population                                  | Pediatric, Adults    | Equipment dosimetry and Examination protocol and equipment QA by the radiation protection team | 20, N/A           | 60, 103       | CT, CT            |
| [11]      | Italy       | 2009 | Descriptive   | Depending on the examination type, between 6% and 51% for one week     | Adults               | Dosimetry of the typical exposures and proportionality factors                     | 10-6332           | 60, 103       | All                |
| [12]      | Taiwan      | 2011 | Survey        | Clinical protocols                                                     | Adults               | Examination protocol and equipment QA by the radiation protection team             | 1                 | 60, 103       | CT                 |
| [13]      | USA         | 2010 | Descriptive   | Emilia-Romagna region                                                  | Adults               | Dosimetry of the typical exposures and proportionality factors                     | 7                 | 60           | Interventional     |
| [14]      | Italy       | 2012 | Descriptive   | 9,681 patients, 22,677 examinations                                    | Pediatric, Adults    | Varies for each type of study                                                      | 36-8781           | 60           | RX, RX/Fluor, CT   |
| [15]      | Spain       | 2008 | Survey        | 50 public hospitals (15%) and 485,000 persons (1%) privately insured    | Adults               | Equipment dosimetry                                                               | N/A               | 60           | RX, CT             |
| [16]      | Austria      | 2014 | Survey        | 10,000 CT examinations                                                 | Adults               | Conversion factor                                                                 | N/A               | 103          | CT                 |
| Year | Country | Examinations | Examination Details | Participants | Measurements | Dosimetry Details | Equipment |
|------|---------|--------------|---------------------|--------------|--------------|------------------|-----------|
| 2010 | Belarus | 8 scanners   | Adults, Equipment dosimetry | Adults | 8 | 60 | CT |
| 2012 | USA     | 120 examinations | Adults, Equipment dosimetry | Adults | 120 | 60 and 103 | CT chest |
| 2011 | Nigeria | 209 examinations | Adults, Equipment parameters | Adults | 20-82 | 60 | RX |
| 2013 | Canada  | Depends on the examination | Adults, Equipment dosimetry | Adults | 4-161 | 103 | RX, CT |
| 2007 | Brazil  | Depends on the examination, 1917 in total | Adults, Equipment parameters | Adults | 85-713 | 60 | RX |
| 2012 | Italy   | 15% of the frequency | Adults, Equipment dosimetry | Adults | 8-11 | 103 | Angiography |
| 2010 | Russia  | 6 hospitals in St. Petersburg | Adults, Equipment dosimetry | Adults | 19-40 | 60 | Interventional |
| 2008 | France  | National health insurance office database | Adults, Equipment dosimetry | Adults | N/A | 60 | RX, CT |
| 2011 | Canada  | 2628 examinations | Adults, Equipment dosimetry | Adults | 2628 | Not specified | Angiography |
| 2007 | Australia | All cases during a 12 months period (2004) | Adults, Conversion factor | Adults | 256-1088 | 60 | Angiography and PTCA |
| 2008 | Australia | All cases during a 12 months period (2006) | Adults, Conversion factor and equipment dosimetry | Adults | 1458 | 60 | Angiography |

(Continued)
| Reference | Country       | Year  | Type of study | Sample                                | Age            | Calculation method                     | Calculation sample | ICRP weights | Included procedures |
|-----------|---------------|-------|---------------|---------------------------------------|----------------|----------------------------------------|--------------------|--------------|---------------------|
| [30]      | USA           | 2009  | Survey        | 1119 examinations adults              | Equipment dosimetry | 120 60 CT                              |                    |              | CT                  |
| [31]      | Sudan         | 2010  | Descriptive   | 445 examinations adults              | Equipment dosimetry | 111 60 CT                              |                    |              | CT                  |
| [32]      | Netherlands   | 2007  | Descriptive   | 10 hospitals adults                  | Varies for each type of study | 16 technicians 60 CT                   |                    |              | RX, CT              |
| [33]      | Japan         | 2010  | Survey        | One month in all of Gunma prefecture (48% of response rate) adults | Equipment parameters | Protocols for 130 scanners 60 CT       |                    |              | CT                  |
| [34]      | Netherlands   | 2013  | Survey        | 186 standard-sized patients adults   | Conversion factor | 19 scanners 103 CT                     |                    |              | CT                  |
| [35]      | Spain         | 2013  | Survey        | 12 x-ray departments all             | Following report 154 | 240 60 All                              |                    |              | All                 |
| [36]      | Switzerland   | 2011  | Survey        | Whole country x-ray departments adults | Following report 154 | N/A 60 and 103 All                     |                    |              | All                 |
| [37]      | Romania       | 2008  | Survey        | 179 x-ray departments all            | Conversion factor | N/A 60 RX, RX/Fluor                    |                    |              | RX, RX/Fluor        |
| [38]      | USA           | 2007  | Survey        | Depends on the examination (6-71)    | Measurements on the equipment and parameters | 265 60 CT         |                    |                      |
| [39]      | UK            | 2011  | Survey        | Depends on the examination           | Varies for each type of study | N/A 60 years 103 RX, RX/Fluor, CT     |                    |              |                      |
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