Estimation of the collective effective dose to the population from medical x-ray examinations in Finland

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Abstract. The collective effective dose to the population from all x-ray examinations in Finland in 2005 was estimated. The numbers of x-ray examinations were collected by a questionnaire to the health care units (response rate 100\%). The effective doses in plain radiography were calculated using a Monte Carlo based program (PCXMC), as average values for selected health care units. For computed tomography (CT), weighted dose length product (DLP\textsubscript{w}) in a standard phantom was measured for routine CT protocols of four body regions, for 80\% of CT scanners including all types. The effective doses were calculated from DLP\textsubscript{w} values using published conversion factors. For contrast-enhanced radiology and interventional radiology, the effective dose was estimated mainly by using published DAP values and conversion factors for given body regions. About 733 examinations per 1000 inhabitants (excluding dental) were made in 2005, slightly less than in 2000. The proportions of plain radiography, computed tomography, contrast-enhanced radiography and interventional procedures were about 92, 7, 1 and 1\%, respectively. From 2000, the frequencies (number of examinations per 1000 inhabitants) of plain radiography and contrast-enhanced radiography have decreased about 8 and 33\%, respectively, while the frequencies of CT and interventional radiology have increased about 28 and 38\%, respectively. The population dose from all x-ray examinations is about 0,43 mSv per person (in 1997 0,5 mSv). About half of this is caused by CT (in 1997 only 20\%) although the relative number of CT examinations is only 7\%. The contribution by plain radiography is 19\%, interventional radiology 17\%, and contrast-enhanced radiology 14\%. It is concluded that CT examinations are the major source of the population dose, while interventional radiology gives about the same population dose as plain radiography. For plain radiography, body examinations cause the highest effective dose.

KEYWORDS: frequency of x-ray examinations, effective dose to population

1. Introduction

The use of radiation for medical diagnostic examinations contributes over 95\% of the man-made radiation exposure and is only exceeded by natural background as a source of exposure [1]. In the next few years, particularly with the rapidly increasing use of computed tomography (CT), the medical use of radiation may exceed natural background as a source of population exposure. In countries with advanced health care systems, the annual number of radiological diagnostic procedures approaches or exceeds one for every member of the population. Therefore, it is of high interest to monitor the examination frequencies and patient doses and observe any trends in their relative number and significance as for the dose to the population. The population dose is important in order to evaluate the overall significance of medical exposure compared with other sources of exposure and to get information on its relative risks as a source of radiation induced cancer and other detriments.

The number of CT examination and interventional procedures are known to be rapidly increasing worldwide and can cause high doses to the patients, in particular if the procedures are not carefully optimized. It is of particular interest, therefore to evaluate the relative importance of these procedures as a source of population dose. In Finland, the latest estimation of collective effective dose to the population from medical x-ray examinations (0.5 mSv/capita [2]) is based on rather old data which is partly more than 10 years old. Therefore, there was a clear need to up-date this value to correspond to the current radiological practices.

2. Purpose

The purpose of this study was to survey the number of x-ray examinations performed in Finland in 2005, to collect information on the patient dose in various types of x-ray examinations and interventional procedures, and to combine these data to estimate the collective effective dose to the population from all x-ray examinations and procedures in Finland. The purpose was also to settle out
the relative importance of various examinations and procedures for the population dose and to evaluate any recent trends by comparing the results with earlier data from Finland.

3. Methods

3.1 Numbers of x-ray examinations

The numbers of x-ray examinations in 2005 were collected by a questionnaire to the 406 health care units registered as safety license holders by the Radiation and Nuclear Safety Authority of Finland (STUK) [3]. The radiotherapy and isotope units were excluded from this inquiry. The inquiry was based on the joint nomenclature [4], which is the examination coding system used in Finland. In the nomenclature the examinations are distributed to plain radiography, contrast-enhanced radiography, angiography, computed tomography and radiological interventional procedures based on the imaging technique utilised. The fluoroscopy examinations without contrast medium are included into plain radiography examinations. In this study, apart from the classification of the joint nomenclature, the contrast-enhanced radiography includes also angiographic examinations. The numbers of examinations have been presented in frequencies, i.e. examinations per one thousand (1000) of population. The population in Finland in 2005 was 5.256 millions.

The trends in radiological practices performed in Finland between 2000 and 2005 were determined comparing the results with the results of a previous nationwide summary conducted by STUK [5].

For the determination of the collective effective dose to the population, the above classification of the examinations was used. The collective effective dose was determined based on both the information about the number of examinations and the effective dose of each type of examination.

3.2 Population dose for plain radiography

For plain radiography examinations, the determination of collective effective doses was made utilising a Monte Carlo based program (PCXMC) [6]. PCXMC is a computer program for calculating patients' organ doses and the effective dose in medical x-ray examinations (radiography and fluoroscopy). The program incorporates adjustable-size paediatric and adult patient models, and allows a free choice of the x-ray examination technique. PCXMC has been developed by STUK for its own research purposes. All the parameters affecting the patient dose (focus to skin distance FSD, radiation quality and output, filtration, field size and the number of exposures in each examination) were computerized and the effective dose was calculated. The effective doses of thorax, abdomen, hip and pelvis examinations are the average doses of the university hospitals, some central hospitals, some regional hospitals and a few health centres in Finland based on an individual inquiry made for 20 imaging centres during the summer 2006. The AP/PA and SS-projections were calculated separately within these four examinations separated from the other examinations, where the effective doses are assumed to be the number of exposures multiplied with the effective dose of the AP/PA-projection. The doses of the other examinations are based on the average of two health centres. The effective doses of some limb examinations were assumed to be similar to each other, in the examinations of the hand and fingers and the wrist, for example. The effects of these assumptions were thought to be diminutive to the collective dose on the whole.

3.3 Population dose for computed tomography

For the most typical CT examinations of head, thorax, abdomen and lumbar spine, with the standard imaging protocol, the weighted dose length product (DLPw) was measured in a standard PMMA phantom using a calibrated pencil ionization chamber. The measurements were carried out using a technique developed at STUK, where the phantom is kept in a fixed position in air in the centre of the CT hole and above the couch, by the help of a special “swing”, while during the measurement the couch is moving below the phantom in accordance with the CT protocol [7]. In this way, the DLPw value for the whole examination will be directly obtained. The measurements covered about 80 % of the CT scanners used in Finland and included all types of equipment (1-, 2-4-, 6-10- and 16-slice
equipment). Average DLP\textsubscript{w} values from the measurements for each type of the CT examination were calculated and converted to effective doses using the conversion factors published by Shrimpton et al. [8].

The average effective doses for each type of CT examination specified in the national classification or coding system were determined based on the imaged body region and taking into account the number of series used (1 or 2). For the CT examinations specified as “very extensive” in the national coding system, the dose was doubled compared with the “extensive” or “normal” examination. The measured DLP\textsubscript{w} values were somewhat dependent on the type of the CT equipment (number of slices); therefore, for the CT examinations which contributed more than 3 % of the total population dose from CT examinations, the effect of the CT equipment were taken into consideration when calculating the population dose.

3.4 Population dose for contrast-enhanced radiology and interventional radiology

For contrast-enhanced radiology and interventional radiology, a number of publications were reviewed and a set of published dose area product (DAP) values, or effective dose values, for a few common examinations or procedures were collected, including some published data from Finland [9-12]. Most of the data was taken from the publications by the NRPB [9] and McParland [10]. For a given body region, the effective doses were calculated from the DAP values by using the conversion factors published by the NRPB [9] or McParland [10]. In some cases, the published effective dose was used directly instead of the conversion from the DAP value.

4. Results and discussion

4.1 Frequencies of x-ray examinations

About 733 x-ray examinations per 1000 inhabitants were made in 2005, which is slightly less than in 2000. The frequencies of plain radiography and contrast-enhanced radiography examinations have diminished about 8 % and 33 % from 2000 to 2005 whereas the frequencies of CT examinations and radiological interventional procedures have increased about 28 and 38 % respectively (Table 1). The proportions of plain radiography, computed tomography, contrast-enhanced radiography and interventional procedures were about 92, 7, 1 and 1 %, respectively (Figure 2).

The frequencies of medical x-ray examinations are also compared with previous data obtained from United Kingdom, Norway, Luxemburg, Switzerland and the average value reported by the UNSCEAR for Healthcare I level countries (Table 2) [1]. The frequencies of x-ray examinations (excluding interventional procedures) and CT examinations are close to the average value for health care level I countries, while the frequency of interventional procedures is significantly higher. However, the latter is in reasonable agreement with more recent data from UK and Luxembourg.

Table 1: Radiological examinations in Finland in 2000 and 2005 per 1000 inhabitants

<table>
<thead>
<tr>
<th></th>
<th>2000</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain radiography</td>
<td>724.1</td>
<td>663.9</td>
</tr>
<tr>
<td>Contrast-enhanced radiography</td>
<td>18.3</td>
<td>12.2</td>
</tr>
<tr>
<td>Computed tomography</td>
<td>39.5</td>
<td>50.4</td>
</tr>
<tr>
<td>Interventional radiology</td>
<td>4.7</td>
<td>6.5</td>
</tr>
</tbody>
</table>
Figure 2: The relative proportions of x-ray examinations performed in Finland in 2005

Table 2: The frequencies (examinations per 1000 inhabitants) of medical x-ray examinations performed in Finland, United Kingdom, Norway, Luxemburg, Switzerland and UNSCEAR Healthcare level I countries on average in 1991-2005 [1].

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>2000</td>
<td>2005</td>
<td>2002</td>
<td>2002</td>
<td>1366</td>
<td>1340</td>
<td>920</td>
</tr>
<tr>
<td>Interventional procedures</td>
<td>4.7</td>
<td>6.5</td>
<td>7.4</td>
<td>9.0</td>
<td>3.8</td>
<td>2.7</td>
<td></td>
</tr>
<tr>
<td>Computed tomography</td>
<td>39</td>
<td>50</td>
<td>26</td>
<td>104</td>
<td>135</td>
<td>46</td>
<td>48</td>
</tr>
<tr>
<td>X-ray examinations (excluding CT/Interventional procedures)</td>
<td>732</td>
<td>676</td>
<td>324</td>
<td>638</td>
<td>707</td>
<td>838</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Population dose for plain radiography

The collective effective dose to the population caused by plain radiography examinations during 2005 in Finland was ca. 0.08 mSv per person, while 664 examinations per thousand inhabitants were made. This is about 19 % from the total dose from all x-ray examinations. The highest contributions came from the body examinations (54 %), mammography (16 %), thorax examinations (13 %) and limb examinations (10 %). The corresponding frequencies were 78, 55, 222 and 223 (examinations per thousand inhabitants), indicating that the plain radiography examinations of the body and the mammography examinations are of more importance on point of view of patient dose even if their frequency is much lower than those of thorax and limb examinations.
4.3 Population dose for computed tomography

The collective effective dose to the population caused by computed tomography was 0.22 mSv per person, while about 50 CT examinations per thousand inhabitants were made. This is about 50 % from the total dose of all x-ray examinations and has been significantly increased from 1997, when it was estimated to be only 20 %. The highest contributions came from the contrast-enhanced CT-examination of the trunk (17 %) and native head CT examinations (15 %). The corresponding frequencies were 3.2 and 19 (examinations per thousand inhabitants), indicating that the CT examinations of the trunk are of more importance on point of view of patient dose even if their frequency is much lower.

4.4 Population dose for contrast-enhanced radiology and interventional radiology procedures

The collective effective dose to the population caused by contrast-enhanced radiology was 0.06 mSv per person, while about 12 examinations per thousand inhabitants were made. This is about 14 % from the total dose of all x-ray examinations. The highest contributions came from coronary angiography (CA; 32 %) and contrast-enhanced examinations of small and large intestine (about 23 %). The corresponding frequencies were 3.1 and 1.9 examinations per thousand inhabitants.

The collective effective dose to the population caused by interventional radiology procedures was 0.07 mSv per person, while about 6.5 examinations per thousand inhabitants were made. This is about 17 % from the total dose of all x-ray examinations. The highest contributions came from PTCA (28 %) while any other IR procedure contributes to less than about 10 % of the total. The frequency of PTCA was about 0.8 procedures per thousand inhabitants.

4.5 Total population dose

The total collective effective dose to the population in Finland in 2005 is 0.43 mSv per person (Table 3), which is a little less than the earlier estimation of 0.5 mSv from 1997. This is much lower than the average value of 1.2 mSv reported for health care level I countries [1]. About half of the total effective dose is caused by CT examinations, while the other contributions vary between 14 and 19 %.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Collective effective dose / person [mSv]</th>
<th>Relative proportion of the total dose [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain radiography</td>
<td>0.08</td>
<td>19</td>
</tr>
<tr>
<td>Contrast-enhanced radiography</td>
<td>0.06</td>
<td>14</td>
</tr>
<tr>
<td>Computed tomography</td>
<td>0.22</td>
<td>50</td>
</tr>
<tr>
<td>Interventional radiology</td>
<td>0.07</td>
<td>17</td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.43</td>
<td></td>
</tr>
</tbody>
</table>

5. Conclusions

The population dose from all x-ray examinations, about 0.43 mSv per person, has slightly decreased from the earlier estimation of 0.5 mSv from 1997 and is much lower than the average value of 1.2 mSv reported for health care level I countries [1]. About half of this is caused by CT (in 1997 only 20 %), although the relative number of CT examinations is only 7 %. The contribution by plain radiography is about 19 %, interventional radiology about 17 %, and contrast-enhanced radiography about 14 %. It is concluded that CT is the major source of the population dose, while interventional radiology gives about the same population dose as plain radiography. For plain radiography, body examinations cause the highest effective dose.
The staff in use of radiation must receive supplementary training enabling their radiation protection knowledge and skills to be kept up to date. The aim of the supplementary training is to increase the knowledge of the doses caused by the medical x-ray examinations to the patients. The significance of the justification and optimisation of the examinations is also impressed. The supplementary training has been implemented in collaboration with the authorities (STUK) and the experts involved in the use of radiation. In addition to the radiation protection training involved in basic training and to regular supplementary training, anyone using a radiation appliance and radiation source shall be familiarized with radiation safe working methods for each procedure, and with the optimal use of the radiation appliance and radiation source.

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REFERENCES


