EVOLUTION OF THE EXCESS ABSOLUT RISK (EAR) IN THE VALENCIAN BREAST CANCER SCREENING PROGRAMME

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Abstract: Breast cancer is one of the most frequent diseases in women, with a high incidence rate. The best fight against the breast cancer is the early detection by means of mammograms in a screening programme. The Valencian Breast Cancer Screening Programme (VBCSP) started at 1992, and it is composed of twenty-two mammography units. The programme is targeted towards asymptomatic women from 45 to 69 years old, but this screening has a negative influence in the studied woman, whatever the diagnosis was. By means of MCNP-4c2 Monte Carlo code, some conversion factors from air kerma to glandular dose have been developed. Different breast woman models, according to the Valencian breast anathomy (taking into account the relation breast radius / breast compression thickness obtained from real samples), have been simulated in order to obtain the glandular breast dose values. Quality control parameters as ESAK values were also employed for developing the methods. The conversion factors give a simple and fast way to obtain the mean glandular dose from mammography exposition parameters. The glandular dose has been also calculated following the European Protocol on Dosimetry in order to compare the results of the new methodology. Four sample populations of 100 women from each unit of the VBCSP have been taken in order to estimate the mean glandular dose and the associated excess absolute risk (EAR). Once the doses for each woman from the samples are obtained and according to the age of them, the EAR value for each sample has been determined following the UNSCEAR 2000 projection risk model, which takes into account the characteristics of the Valencian population and gives the EAR for radio-induced breast cancer. The results have been calculated and compared by means of the ASQRAD software, but with an older risk projection model, the UNSCEAR 1994. Once the four sample average EAR have been calculated, the evolution of the induced risk in the Valencian Breast Cancer Programme has been determined.
1. Introduction

It is well known that the best way to fight against diseases is prevention. Breast Cancer Screening Programs are used as an early detection technique in many countries. Although these programs reduce breast cancer mortality, radiation presents health risks for women undergoing screening.

In 1992, the Valencian Breast Cancer Screening Program (VBCSP) [1] started in the Valencian Community, a region of Spain with about four and half million of inhabitants. Up to now, twenty-four mammography units are installed in public hospitals, all over the region. The VBCSP is directed towards asymptomatic women between 45 and 69 years old, with an initial age lower than other programs in the country. In the VBCSP, the screening examination consist of two mammograms, craniocaudal (CC) and oblique view (OBL) of each breast the first time that the woman participates in the program and a single mammogram (OBL) in subsequent rounds. The screening interval in the VBCSP is two years and each view is read only by one radiologist.

Mean glandular dose (MGD) in a breast has been widely accepted as the effective dose absorbed in mammography. In order to calculate this mean glandular dose and its Excess Absolute Risk (EAR) associated in the VBCSP, four samples of 100 women from each unit of the program were taken. By means of the MCNP-4C2 Monte Carlo code and the real mammographic exposure conditions of the sample, the value of the induced dose is calculated for each exposure. This dose has been also calculated following the European Protocol on Dosimetry in Mammography [2] in order to compare the obtained results. The UNSCEAR 94 report (ASQRAD software) [3] and the UNSCEAR 2000 report [4] have been used to obtain the Excess Absolute Risk per women-year of the sample population.

2. Method

2.1. Mean glandular dose calculation.

The European Protocol and MCNP conversion factors have been used for calculating the average mean glandular doses of the samples taken.

The conversion factors have been developed by means of Monte Carlo techniques using real data from the screening program in study, such as quality control parameters and Valencian breast morphology. This method consists of three conversion factors between dosimetric quantities. The methodology will be validated by comparing with the method presented in the European Protocol on Dosimetry in Mammography, considering additional factors published after its publication [5].

The dosimetric analysis, is based on modeling the conditions during the mammography, considering different tube voltages, breast thickness, radii and glandularities. The simulation was performed by means of the radiation transport MCNP-4C2 code.

The entrance surface air kerma ($ESAK$) is defined as the incident air kerma measured in quality controls free in air without backscattering and it is obtained with an ionization chamber, placed below the upper compression plate. A similar quantity used in this paper, is $ESAK_c$, which is defined as the interpolated incident air kerma in the breast entrance surface.

The $ESAK_c$ is decomposed of two factors

$$ESAK_c = \Gamma_{FDD}(kV) \left( \frac{FDD}{FFD-s_b} \right)^2 mAs \tag{1}$$

where $\Gamma_{FDD}$ is the incident air kerma at the focus-detector distance ($FDD$) per unit of tube load, measured during the quality control realization, $FFD$ is the focus-film distance, $s_b$ is the compressed...
breast thickness and mAs is the X-ray tube load during a routine exposure. It has been considered the constant distance difference between the focus-film and the focus-detector, in quality control, of 4.5 cm, and the detector displacement, at 6 cm from the chest wall.

Since measured values of the half value layer (HVL) were obtained for each unit only at a nominal voltage (kV\text{nom}), the variation of HVL with voltage obtained from a fit of data from the European Protocol on Dosimetry in Mammography, with a molybdenum target and a 0.03 mm molybdenum + 3 mm polymethyl-methacrylate filtration, were used to predict the HVL at other kV values. The relationship that was obtained was

\[
HVL(kV) = \frac{HVL_{\text{measured}}}{kV_{\text{nom}}} \left( A_1 kV^2 + A_2 kV + A_3 \right) \]

where kV is the mammographic voltage used, kV_{\text{nom}} is the nominal voltage value and \( A_1 = -0.0005, A_2 = 0.0339 \) and \( A_3 = -0.2191 (R^2 = 0.9943) \).

The mean glandular dose per mammogram has been calculated, according to the expression

\[
MGD = f_{\text{ESAK}} = f_K f_{\text{TD}} f_{\text{GD}} \text{ESAK} e
\]

The \( f_K \) factor is defined as the ratio of the incident kerma with and without backscatter and it is obtained from MCNP-simulation results, in MeVg\text{^{-1}}photon\text{^{-1}}. This factor has been calculated as a function of the half value layer (HVL), taken from the European Protocol for each kV value, and the compressed breast thickness (s_b), and is given by

\[
f_K(HVL, s_b) = \frac{\text{Kerma with backscatter (model 1) MeVg}^{-1}\text{photon}^{-1}}{\text{Kerma without backscatter (model 2) MeVg}^{-1}\text{photon}^{-1}}
\]

In order to calculate the previous factors, two MCNP models have been employed. Model 1 defines the conditions during a routine mammography exposure, whereas model 2 defines the conditions during the ESAK measurements in quality control performance, free in air. The female breast used in the model 1 is a semi-cylinder with a variable outer radius and a variable adipose tissue outer layer, depending on the compressed breast thickness, in a range from 0.5 to 11 cm. The geometric model properties have been obtained from over 600 CC and OBL view samples. A least square adjustment has been made to predict the trend in the average value of the breast radius (R_{out}), depending on the compressed breast thickness (s_b), as showed in expression

\[
R_{out} = B_1 s_b + B_2
\]

with \( B_1 = 1.1416 \) and \( B_2 = 5.5933 (R^2 = 0.94695) \). The hypothesis of an 8 cm radius (European Protocol radius hypothesis) does not predict in a suitable way the Valencian breast morphology. Both models include the upper compression plate.

The \( f_{\text{TD}} \) factor is defined as the ratio of the mean total dose and the incident kerma obtained by simulation. It has been calculated as a function of the HVL and the compressed breast thickness (s_b) and it is given by

\[
f_{\text{TD}}(HVL, s_b) = \frac{\text{Mean total dose in breast (model 1) MeVg}^{-1}\text{photon}^{-1}}{\text{Kerma with backscatter (model 1) MeVg}^{-1}\text{photon}^{-1}}
\]

Breast glandularity (G_K) has been assumed as a function of the age at exposure [6]. The \( f_{\text{GD}} \) factor is given by the ratio between mean glandular dose and total breast dose, function of compressed breast thickness (s_b) and G_K and is given by
The MCNP code does not allow the separation of doses in the glandular and the adipose tissues that compound a cell. It has been assumed that the glandular dose is the addition of the atomic contributions of the doses absorbed by each element in the glandular tissue, defined as

\[ d_g = \sum_{i=1}^{4} \%_{gi} d_i \]  

(8)

where \( d_i \) is the single contribution to dose of the element \( i \) (oxygen, carbon, nitrogen and hydrogen) obtained directly from the MCNP-4C2 output as average flux in a cell, and \( \%_{gi} \) is the percentage of element \( i \) in the glandular tissue.

In the **European Protocol method**, a single factor, \( g \), dependent only on compressed breast thickness and \( HVL \) is used. To validate the conversion factors methodology, a comparison between both methods has been made.

European Protocol follows the methodology presented in 1990 by Dance et al [8]. At this time, glandular dose was calculated without taking into account the glandularity deviation. According to the additional factors presented by Dance et al in 2000, the mean glandular breast dose expression (MGD) is given by

\[ MGD_{2000} = gcs \cdot ESAK_a \]  

(9)

where the factor \( c \) corrects for any difference in breast composition, compared with the standard breast (50/50) glandularity and the factor \( s \) corrects for any difference due to the use of a different X-ray spectrum, whereas the factor \( g \) is unchanged, and obtained to a larger breast thickness range. These conversion factors have been adjusted to non-linear expressions in order to be applied to the calculation of every mammogram dose.

Once the mean glandular dose per mammogram has been calculated, the Average Mean Glandular Dose (AMGD) for each one of the samples has been determined as it follows

\[
AMGD(i) = \frac{1}{2 \sum_{j=1}^{nu(i)} \sum_{k=1}^{nw(i,j)} \sum_{l=1}^{nv(i,j,k)} MGD(i, j, k, l) \cdot f_G(i, j, k, l) \cdot f_D(i, j, k, l) \cdot f_{GD}(i, j, k, l) \cdot ESAK(i, j, k, l)}{nu(i)}
\]

(10)

where \( nu(i) \) is the number of units contributing to dose in the sample population \( i \), \( nw(i,j) \) is the maximum number of women in the considered unit \( j \) in the sample \( i \) and \( nv(i,j,k) \) is the maximum total number of mammograms for the woman \( k \) in the unit \( j \) in the sample population \( i \).
2.2. Estimation of the excess absolute risk in the VBCSP (\( \text{EAR}^{\text{VBCSP}} \))

The UNSCEAR 1994 report shows the radiological risks due to ionizing radiation exposures in a population which has received a determined dose level. This report took into account most of the external low-LET studies of radiation-induced cancers such as the incidence and cancer mortality until 1987 of survivors from atomic bombs in Hiroshima and Nagasaki, patients exposed to radiation in diagnosis and workers from radioactive facilities.

The UNSCEAR 2000 report has been recently published. It contains the observed and expected number of cases for breast cancer incidence and mortality. New findings include those from the extended follow-up for mortality of the Japanese atomic bomb survivors. However, as a consequence of the high cure rate for this type of cancer, the results for cancer incidence in the studied cohort are probably of great importance, despite the slightly shorter follow-up period for incidence than for mortality. New results have also been reported from a number of studies, including the extended follow-up of Swedish patients irradiated skin haemangiona in infancy, incorporating individual estimates of organ doses and patients from both Stockholm and Gothenburg [9], [10], [11].

In this study, it has been considered an age at exposure model; therefore the site-specific solid cancer risks estimated as the \( \text{EAR}^{\text{VBCSP}} (e) \) at an age-at-exposure \( e \) is calculated by the expression

\[
\text{EAR}^{\text{VBCSP}} (e) = \int_{e+L}^{e+P} h_{0}^{\text{VBCSP}} (a') \text{ERR} (e) da' \approx \text{ERR} (e) \sum_{j=e+L}^{e+P} \left( \prod_{k=e}^{j-1} \left( 1 - h_{0}^{\text{VC}} (k) \right) \right) h_{0}^{\text{VC}} (j)
\]

where \( L \) and \( P \) are the latency period and the plateau for breast cancer, respectively, \( e \) is the age at exposure, \( h_{0}^{\text{VC}} \) is the mortality rate of the Valencian Community women population, due to all causes, including other breast cancer mortality rates. The latency period and the plateau are obtained through the data presented in the ICRP (1991) morbidity data [12].

The \( \text{ERR} \) has been fitted to observed data, depending on the risk model (UNSCEAR 94 or UNSCEAR 2000). Thus, the \( \text{EAR}^{\text{VBCSP}} \) has been calculated following both models. Figures 1 and 2 show the excess absolute risk in terms of the probability of radiation induced breast cancer per (\( \text{PYmSv} \)) applied to the Valencian Community population.

\[\text{Figure 1.- Excess absolute risk per 100000 woman-year at 1 mSv (UNSCEAR 1994 - ASQRAD)}\]
Once the EAR has been determined, it is necessary to quantify the mean cancer induction rate or detriment. For this purpose it is assumed the average mean glandular dose (AMGD) applied to the whole population taking into account the percentage of women and the $EAR_{VBCSP}^{}$ for each age group under screening. The results for each sample will be given by

$$\Omega_{fbc}^{VBCSP} = ADMG \sum_{j=45}^{65} EAR_{fbc}^{VBCSP} (j) \%_{j}$$

where $ADMG$ is the average mean glandular dose from each sample. $EAR_{fbc}^{PPCMCV}$ $(j)$ is the Excess Absolute Risk in fatal breast cancers in the age group $j$ and $\%_{j}$ is the percentage of age $j$ women in the Valencian Community.

3. Results & discussion

Mean Glandular Doses have been calculated for every one of the four samples. This calculations have been made in two ways: by screening unit and by age group (necessary to the later calculation of the Excess Absolute Risk). Figures 3 and 4 show these results corresponding with the four sample, extracted in 2003.
Figure 4: Mean Glandular Dose per mammogram in mSv for every age group considered in the VBCSP

If dose results are closely analyzed, they show a large variance in the average glandular dose between the several units of the Valencian Breast Cancer Screening Program (VBCSP), this is due to the different operation ways in each center. If the data are analyzed by age group (including data from all centers) the results are more uniform.

The large variation in the average glandular dose per unit demonstrates the need of continuous quality control in a breast cancer screening program. As the number of units employed increases, the difficulty of equalising the procedures becomes unattainable without a centralized control, thus the implementation of a quality control system is very important for any breast cancer screening program.

Table 1 shows the average value of mean glandular dose per mammogram in each sample population for the conversion factors and the European Protocol method. As it can be noticed, from one sample to the following dose results are decreasing in time after each quality control round.

Table 1: Average mean glandular dose by the MCNP conversion factors and European Protocol methods. Number of women and views for each sample.

<table>
<thead>
<tr>
<th>Population Sample</th>
<th>Nº women</th>
<th>Nº views</th>
<th>AMGD-MCNP Conversion Factors (mSv)</th>
<th>AMGD-E.P. (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; sample</td>
<td>2222</td>
<td>6117</td>
<td>$1.569 \pm 0.759$</td>
<td>$1.526 \pm 0.743$</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; sample</td>
<td>1889</td>
<td>4958</td>
<td>$1.425 \pm 0.593$</td>
<td>$1.393 \pm 0.599$</td>
</tr>
<tr>
<td>3&lt;sup&gt;rd&lt;/sup&gt; sample</td>
<td>1799</td>
<td>4881</td>
<td>$1.249 \pm 0.486$</td>
<td>$1.238 \pm 0.507$</td>
</tr>
<tr>
<td>4&lt;sup&gt;th&lt;/sup&gt; sample</td>
<td>2010</td>
<td>4636</td>
<td>$1.201 \pm 0.436$</td>
<td>$1.181 \pm 0.454$</td>
</tr>
</tbody>
</table>

In Table 2 are presented the Excess Absolute Risk (EAR) results for every risk model (UNSCEAR 94 and 2000) and for the two calculation methods considered (conversion factors and European Protocol). As it can be seen, risk values are decreasing as the dose values showed before. In approach, fatal cancer risk value is half of the total risk value. A noticeable difference is present between the models UNSCEAR 94 and UNSCEAR 2000, being UNSCEAR 2000 values much higher than the other one. This is due to the epidemiological data considered, while UNSCEAR 94 is based only on the radiation incidence of Japanese atomic bomb survivors from Hiroshima and Nagasaki, UNSCEAR 2000 model...
takes into account other cohorts, these are the extended follow-up for mortality of the Japanese atomic bomb survivors, the extended follow-up of Swedish patients irradiated skin haemangioma in infancy and patients from both Stockholm and Gothenburg.

Table 2: Excess Absolute Risk in Total and Fatal Breast Cancer per 100,000 women for the UNSCEAR 94 and 2000 model risks

<table>
<thead>
<tr>
<th>Sample population</th>
<th>Risk model</th>
<th>MCNP Conversion Factors</th>
<th>European Protocol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total cancer</td>
<td>UNSCEAR 94</td>
<td>UNSCEAR 2000</td>
</tr>
<tr>
<td>1st sample</td>
<td></td>
<td>1.216</td>
<td>2.723</td>
</tr>
<tr>
<td></td>
<td>Fatal cancer</td>
<td>0.608</td>
<td>1.362</td>
</tr>
<tr>
<td>2nd sample</td>
<td>Total cancer</td>
<td>1.125</td>
<td>2.510</td>
</tr>
<tr>
<td></td>
<td>Fatal cancer</td>
<td>0.562</td>
<td>1.255</td>
</tr>
<tr>
<td>3rd sample</td>
<td>Total cancer</td>
<td>0.972</td>
<td>2.179</td>
</tr>
<tr>
<td></td>
<td>Fatal cancer</td>
<td>0.486</td>
<td>1.089</td>
</tr>
<tr>
<td>4th sample</td>
<td>Total cancer</td>
<td>0.949</td>
<td>2.117</td>
</tr>
<tr>
<td></td>
<td>Fatal cancer</td>
<td>0.474</td>
<td>1.058</td>
</tr>
</tbody>
</table>

Figure 5 shows the evolution in time of the Excess Absolute Risk calculated with conversion factors dose. Both risk models are presented.

Figure 5: Evolution of the Excess Absolute Risk (EAR) per 100,000 women in total and fatal cancers for the VBCSP. Values obtained using UNSCEAR 94 and UNSCEAR 2000 projection risk models.
4. Conclusions

This work has studied the radiation risk associated with a breast screening program. The mean glandular dose per unit is an objective value to make comparisons between units in a breast screening program. Also, the Monte Carlo models are very useful to analyze contributions to glandular doses, and its relation with the quality control of the mammography equipment.

The large variation of the average glandular breast dose per mammogram comparing units in a same sample population demonstrates the need of a continued quality control in the Valencian Breast Cancer Screening program. In few units of the first sample population, the average glandular doses have been lower than 1 mSv per mammogram. The need of a continued following of dose measurements is essential to improve the quality level in a breast screening program.

The excess absolute risk measured as number of fatal cancers number induced by the mammography is lower than 0.7 per 100000 exposed women for the model UNSCEAR 94 and lower than 1.4 per 100000 women for the more conservative model, UNSCEAR 2000. Furthermore, as a consequence of the dose reduction, the radiological risk has diminished from sample to sample. These results show that it is possible to reduce the radiological risk by making reviews and equalizing procedures. In this line, studies are being carried out to analyze and to optimize the ratio of screen-detected cancers per screen-induced cancers, focused to increase the image quality, for a better radiologist interpretation, through a reduction in the average glandular breast dose.

5. References


7. ‘Catalogue of Diagnostic X-Ray Spectra and other Data’ © The Institute of Physics and Engineering in Medicine ISBN 0 904181 88X


