Assessment of Doses Received By Premature Babies In Their First Months of Life

Thierry-Chef, I.¹,², Maccia, C.¹, Tirmarche, M.², Laurier, D.²

¹Centre d'Assurance de qualité des Applications Technologiques dans le domaine de la Santé, 43 Bd Maréchal Joffre, 92340 Bourg-la-Reine, France. E-mail : MCarlo@compuserve.com
²Institut de Radioprotection et Sûreté Nucléaire, IRSN/DRPH/SRBE/LEPID, B.P.17, 92262 Fontenay-aux-Roses, France. E-mail : margot.tirmarche@irsn.fr

Abstract
Premature babies often need to be treated for respiratory or digestive diseases in neonatal intensive care units. Incidentally, frequent radiological examinations such as chest or abdomen are being performed during their medical follow-up. Furthermore, those patients who have clinical complications may require a complementary period of hospitalisation lasting, in few cases, several months later. Additional X-ray examinations, which often result in higher doses, can also be carried out during this period. With the view of establishing a baseline framework for a possible epidemiological study and in order to assess the potential increased risk among the population of premature babies due to these cumulative exposures, a dosimetric study was carried out in collaboration with both intensive care unit and radiology department of Trousseau Hospital in Paris in 2002.

Entrance surface doses were measured by thermoluminescent dosimeters stuck on patient's skin at the centre of the incident beam while radiographs were being taken. In parallel, doses due to other types of examinations were assessed from the X-ray tube parameters. Individual cumulative doses received over the period of stay were estimated, for each premature baby born in 2002, taking into account the number of examinations which they underwent. Results showed that, even if the average dose per radiograph was relatively low (average entrance dose, effective dose and bone marrow dose of 70 µGy, 25 µSv, 6 µSv, respectively), the cumulative dose strongly depended on the length of stay. The average cumulative effective dose was close to 1 mSv. In some extreme cases, characterized by severe health complications and requiring several months of hospitalization, the cumulative effective dose reached about 20 mSv. This work constitutes a preliminary step towards the assessment of the feasibility of an epidemiological study dealing with the premature babies’ population and highlights the need for the optimization of the radiographic techniques and radiation protection for this particular population.

1. Introduction

By definition, prematurity occurs when a pregnancy lasts fewer than 37 weeks but its characteristics have changed in the past 10 years since, through recent medical progress, the proportion of Low Birth Weight infants (LBW), born before 32 weeks of gestational age, has increased. As a result, conditions of care have evolved and these premature babies require special treatment, as their internal organs are not fully developed. They are treated, sometimes for several months, in Intensive Care Unit (ICU) where environmental conditions are adapted to their needs: incubators are used to maintain a stable temperature, the access is regulated in order to minimize the risk of infection, nutrition and treatment are adapted and surveillance is constant. Among the main pathologies, respiratory and digestive diseases are of great concern and improvement due to treatments is constantly checked by frequent chest and abdomen radiographs. Depending on pathologies, premies may also be transferred in other departments, where they can undergo additional radiological examinations before leaving the hospital, several months after birth.

In Intensive Care Unit, radiographs are taken with a mobile x-ray device the technical parameters of which (kV and mAs) are set, by radiographers, depending on baby’s weight. Unfortunately, mobile devices are not originally designed for paediatric patients and the selection of tubes physical parameters (kV and mAs) may not be optimised and may not fit to the small size of premature babies. Furthermore, these patients, when treated in other hospital departments, are submitted to supplementary complicated radiological examinations such as barium studies, intravenous urography or even CT scanners, which in general, deliver much higher doses.

Because of these different radiological practices, babies are frequently exposed to ionising radiation and optimization of exposure is therefore an essential goal to be achieved in order to minimize doses
received by such radio-sensitive patients [1]. International recommendations have been published\(^1\) in order to provide guidance to maintain appropriate image quality while keeping dose per examination as low as reasonably achievable. Although there is no doubt on the enormous benefit associated to the use of modern imaging techniques in diagnostic radiology, some questions may be raised regarding the potential increase of cancer risk, such as leukaemia, because of the high frequency of examinations performed in the course of premature babies’ treatment.

In this context, a study was set up in order to assess the level of cumulative doses received by premature babies during their first months of life, while hospitalized. The study was conducted in collaboration with the Intensive Care Unit and the Radiology Department of Trousseau Hospital in Paris (France). This study provided a preliminary set of data allowing discussing the relevance of setting-up an epidemiology study on potential increased cancer risk of this population.

2. Material and method

Nearly 500 children are treated each year in the Intensive Care Unit of Trousseau Hospital and among them approximately 100 babies are premature. The evaluation of doses (entrance surface dose, bone marrow dose and effective dose) received by these babies was carried out on those who were admitted in the unit in 2002.

The PCXMC program was used to calculate, from entrance surface dose, bone marrow and effective doses [2]. With this program, organ doses are assessed by Monte-Carlo calculation, which simulate energy deposition in different organs depending on morphological characteristics of the patient (weight and size).

For each premature baby, the overall cumulative dose was calculated taking into account the number and types of examinations performed during their stay in the hospital. The study was conducted in two steps: the first one dealt with dose received in the Intensive Care Unit (mainly due to chest and abdomen radiographs) and the second one with dose due to additional examinations performed in other departments. Dose per radiograph in the Intensive Care Unit was obtained from a series of “in-vivo” measurements, and dose per examination in other departments was exclusively evaluated considering tube physical parameters actually used by radiographers (kV and mAs).

2.1. Dose per radiograph in the Intensive Care Unit

Three categories of birth weight were considered in the study: 500-1500g (category 1), 1500-2500 g (category 2) and babies with weight exceeding 2500 g (category 3). Forty babies were included in the study (at least 10 babies for each weight category) and, for each of them, the entrance surface dose was measured using a thermoluminescent dosimeter (Harshaw FLi-100), stuck on baby’s skin. An average dose per type of radiographs (chest or babygram) was calculated per category of weight, thus allowing the calculation of cumulative dose to be made.

2.2. Dose per examination performed in other departments

A variety of radiological examinations such as simple radiographs (chest, abdomen, head, pelvis) and more complex exams (barium or water-soluble enema, study of oeso-gastric transit, cystography) are routinely performed within the Trousseau Radiology Department on 6 X-ray tables. For each table, Quality Control tests were carried out to check the kV and exposure-time accuracy, tube output and HVL. In order to assess the entrance surface dose for each examination type, the parameters considered (kV and mAs) were those displayed at the control panel level for different babies’ weight. The total entrance surface dose per examination was then calculated, taking into account all X-ray projections. As far as the CT scanner doses are concerned, data published in the literature were used [3-5].

\(^1\)Council directive 97/43 Euratom
2.3. Cumulative doses

The total number of examinations performed on each baby was assessed through the information recorded at the Radiology Department. The overall individual cumulative dose (in terms of entrance surface dose, bone marrow dose and effective dose) was then calculated as the sum of doses due to all types of examinations (radiographs performed in Intensive Care Unit and examinations performed in other departments).

3. Results

3.1. Dose per examination type

3.1.1. “In-vivo” measurements

The main results of measurements performed with TLD stuck on baby’s skin are summarized in FIG. 1. As it can be seen, entrance surface doses ranged from 25 to 180 µGy. All weight categories together, the mean entrance dose was 70µGy and the third quartile value was 90 µGy; this latter being slightly greater than the reference dose value recommended by the European Commission (80µGy) [7], thus suggesting a possible optimization of the practice from the radiological protection point of view. Further details on these results are available elsewhere [8].

![FIG. 1. Histogram of entrance surface doses per radiographs](image)

3.1.2. Dose due to other types of examinations

Doses per examination averaged over all patient weights and ranked as a function of the decreasing entrance surface dose are given in Table I below. As one might expect, the more complex examinations, the higher the entrance surface dose. As far as effective dose is concerned, the more irradiating examinations are those involving large X-ray fields and several organs, such as enemas and oeso-gastric transits.
Table I. Average doses by radiological examination performed in the Radiology Department

<table>
<thead>
<tr>
<th>Type of examination</th>
<th>Entrance surface dose (mGy)</th>
<th>Bone marrow dose (mSv)</th>
<th>Effective dose (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barium enema</td>
<td>10.90</td>
<td>0.87</td>
<td>2.83</td>
</tr>
<tr>
<td>Oeso-gastric transit</td>
<td>10.53</td>
<td>0.91</td>
<td>2.60</td>
</tr>
<tr>
<td>Ribs</td>
<td>6.80</td>
<td>0.38</td>
<td>1.34</td>
</tr>
<tr>
<td>Cystography</td>
<td>6.40</td>
<td>0.41</td>
<td>1.11</td>
</tr>
<tr>
<td>Swallowing</td>
<td>5.94</td>
<td>0.43</td>
<td>1.17</td>
</tr>
<tr>
<td>Water-soluble enema</td>
<td>5.87</td>
<td>0.40</td>
<td>1.30</td>
</tr>
<tr>
<td>Small intestine transit</td>
<td>5.19</td>
<td>0.59</td>
<td>1.81</td>
</tr>
<tr>
<td>Head</td>
<td>2.77</td>
<td>0.23</td>
<td>0.13</td>
</tr>
<tr>
<td>Skeleton</td>
<td>2.53</td>
<td>0.21</td>
<td>0.40</td>
</tr>
<tr>
<td>Spine</td>
<td>0.84</td>
<td>0.07</td>
<td>0.30</td>
</tr>
<tr>
<td>Pelvis</td>
<td>0.29</td>
<td>0.01</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Depending on the anatomical region examined (head, trunk, abdomen or chest), doses from CT scanners were considered to vary between 1 and 4 mSv [3-5].

3.2. Cumulative dose

The radiological history of 125 premature babies (55 girls and 70 boys) treated in the Trousseau Intensive Care Unit was analysed. The average length of stay within this department was 7 days; during this period, babies underwent 9 radiographs. A great variety was found in terms of length of stay (from 1 to 74 days), resulting in a large number of radiographs performed per baby (up to 106). Among the premature babies involved in the study about 30% were low birth weight babies (i.e. born before 32 weeks of gestational age). Their stay in the Intensive Care Unit was longer than the average (24 days) and consequently the average number of examinations performed was higher (25 instead of 9 radiographs).

After the period within the Intensive Care Unit, 46% of premature babies were transferred in other departments where they were treated on average for 1.5 month, with a maximum length of the stay of 14 months.

Individual cumulative doses (entrance surface dose, bone marrow dose and effective dose) are given in Table II. The average individual effective dose cumulated over the period of stay in the Intensive Care Unit represents 20% of the average annual dose due to medical practices in the general population (1mSv) [9]). Depending on the length of stay in the Intensive Care Unit, this cumulative dose may vary between 0.02 and 2.8 mSv. The overall cumulative effective dose is, on average, 1.22 mSv which is of the order of the average annual dose received by the general population. The highest individual cumulative dose (nearly 20 mSv) corresponds to the longest period of stay (14 months) during which several examinations (simple and complex) were performed.

Table II. Cumulative doses from radiographs taken in the Intensive Care Unit and total cumulative doses.

<table>
<thead>
<tr>
<th>Cumulative doses</th>
<th>Radiographs in ICU</th>
<th>Other examinations</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>min-max</td>
<td>mean</td>
</tr>
<tr>
<td>Entrance surface dose (mGy)*</td>
<td>0.61</td>
<td>0.06-8.84</td>
<td>2.54</td>
</tr>
<tr>
<td>Bone marrow dose (mSv)*</td>
<td>0.05</td>
<td>0.01-0.79</td>
<td>0.22</td>
</tr>
<tr>
<td>Effective dose (mSv)*</td>
<td>0.21</td>
<td>0.02-2.81</td>
<td>1.01</td>
</tr>
</tbody>
</table>

* Summed up the total number of projections
As already mentioned, the group of low birth weight infants (category 1) stayed within the Intensive Care Unit longer than the average length of stay. As shown in Figure 2 below, the breakdown of the effective dose due to additional examinations, performed in other departments, was also more important for this category of babies (almost 50% of the total dose). This group of babies was clearly more exposed than the other two groups. Such a trend clearly shows the need for a careful assessment of exposure of low birth weight babies in order to better estimate their potential risk associated to such a radiological practice.

![FIG. 2: Breakdown of effective doses cumulated over the stay in the Intensive Care Unit and in other departments, by category of birth weight](image)

4. Discussion

The study presented here was carried out in order to assess the level of doses received by premature babies because of radiological procedures performed to ensure their health conditions and the effects of the treatment. The main concern arose from the simple observation that in the Intensive Care Unit, radiographs are performed on a daily frequency, which might result in non-negligible doses. The study therefore started from the Intensive Care Unit, where a detailed evaluation of doses was set-up. First, measurements provided doses per type of radiographs for 3 categories of weight. From these, cumulative doses were calculated for all children entering the unit in 2002. The necessary information was found available in the Radiology Department. The careful analysis of this information revealed that the radiological history of premature babies was not just due to radiological practices carried out within the Intensive Care Unit but very often babies were transferred in other services were additional examinations were asked for. It was decided to carry on with a complementary study in order to assess doses cumulated over the whole stay in hospital. Doses per examination type were assessed, depending on babies weight and they were combined with the previous cumulative doses. Knowing that doses due to additional examinations are less reliable than the “in-vivo” measurements performed the Intensive Care Unit, they were nevertheless estimated from measurements of the tube output and considering radiological procedures implemented, depending on babies’ weight.

Cumulative dose received in the intensive care may, in few months, reach (and in rare cases, exceed) the average dose received by the general population in one year. Cumulative doses are multiplied by a factor of 6 if all examinations performed in the hospital are taken into account.

Based on the analysis of recorded files, different groups of premature babies were identified:
- Babies born just before 37 weeks who stayed only few days in the Intensive Care Unit. Cumulative doses for these babies were relatively low;
• Low birth weight babies who were treated for several weeks (or even several months) in the Intensive Care Unit. They were then treated in other departments where additional types of examinations (CT scanners for example) were performed, which resulted in high doses. This group of babies has therefore been identified as a subgroup of patients with higher exposure than the general population. A specific concern arises because these babies are exposed in the very beginning of their life, when their organs are still under development.

5. Conclusion

Doses delivered to premature babies in their first months of life were assessed with the view of evaluating the feasibility and relevance of an epidemiological study on cancer risk among these babies. The level of doses due to radiological practices on premature babies, from this study, would result on an estimated risk of fatal childhood cancer between 3 to 16 per 100,000 children if the ICRP values derived for In-Utero irradiation were considered (from $2.8 \times 10^{-2}$ to $13 \times 10^{-2}$ Sv $^{-1}$) [10]. Using these risk coefficients may lead to an overestimation of the risk as the comparison with a foetus is less relevant several weeks (or months) after birth, since these babies have grown up. In terms of epidemiology, it is very important to assess the risks specifically on very low birth weight babies, as the effects of radiation on these immature patients has not been studied yet. Furthermore, international protection standards applied to the general population have been derived from studies on the atomic bomb survivors, based on models to extrapolate short term high level exposures to low dose-rate exposures. These models are subject to controversies and many epidemiology studies (on both workers and patients) are currently set up in order to directly estimate the effects of fractionated exposure to low dose of ionising radiation. A large scale epidemiology study on premature babies could help in providing complementary information on the effects of fractionated exposure.

References

8. Thierry-Chef, I., Maccia, C., Laurier, D., et al., Radiation Doses Received by Premature Babies in Intensive Care Baby Unit. J. Radiol., (under publication)