Experiences in determining fetal doses from diagnostic radiological procedures and the development of recommendations for the physician caring for the patient are shared.

Determining and Reporting Fetal Radiation Exposure from Diagnostic Radiation

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Abstract: Pregnant women are sometimes exposed to diagnostic ionizing radiation for any number of legitimate medical reasons. When this occurs, it is important to perform an accurate fetal dose estimate using standard methodologies as quickly as possible and to convey this information to the woman's physician, along with a summary of appropriate published medical guidelines. This will provide the physician and the patient with the information necessary to make an informed decision regarding the potential impact of this radiation exposure on the pregnancy. At the same time, it is important to recognize that not all pregnancies end well, and there is a finite chance that legal action could ensue because of this, even if radiation exposure was negligible. For this reason, it is also important to make sure that standard, accepted protocols are followed in calculating radiation exposure and the health physicist provide advice only in his or her areas of competence. Health Phys. 79(Supplement 2):S85-S90; 2000

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INTRODUCTION

In spite of the best efforts of medical practitioners to identify pregnant women prior to administering x rays, fluoroscopy, CT, diagnostic nuclear medicine, or other procedures, some pregnant women nonetheless are subject to these procedures. In some cases, women arrive unconscious following an automobile accident and receive a predetermined "trauma series" of x rays immediately upon arrival. These may be followed by CT if internal injuries seem likely. In such cases, the patient's health depends on accurate information about potential injuries and, in fact, if the woman's life is at risk, even knowledge of pregnancy would not lessen the need for such procedures. In other cases, a pregnancy test administered prior to the procedures may have indicated negative (i.e., no pregnancy) while a post-procedure pregnancy test is positive.

In any case of known or possible fetal exposure to ionizing radiation, it is appropriate for the hospital's Radiation Safety Unit to perform a fetal dose estimate and to convey the results of this estimate to the woman's physician. In addition, it is imperative to also provide sufficient information that the physician can make an informed recommendation to the woman, based on sound, up-to-date information and the recommendations from recent medical literature.

In addition to properly calculating and reporting fetal radiation dose, the health physicist must remember that there is a finite chance that any pregnancy will end in either miscarriage or in a baby with some sort of birth defect, regardless of the possible effects of exposure to diagnostic radiation. This raises the specter that, at some time, a hospital or health physicist could be held responsible for not recommending terminating a pregnancy in the wake of such exposure, in spite of having made the "correct" decision based on dose calculations and recommendations in the medical literature. Because of this, it is also important to develop a methodology for performing dose calculations, a standard letter and information package to present to physicians, and a current set of references upon which to base both calculations and reporting. It is also important to consult with the hos-
pital legal counsel to ensure that the hospital and Radiation Safety Unit are protected in the event of such an occurrence. All of these issues will be discussed in the following paper.

Note: At various stages of development the terms “embryo,” “fetus,” “blastula,” and others are used, each with a precise meaning. Rather than trying to use each term properly in the rest of this paper, I will use the more general term, “conceptus,” regardless of the developmental stage.

EFFECTS OF EXPOSURE TO IONIZING RADIATION ON THE CONCEPTUS

Several excellent references are available that discuss these effects in great detail. This section will not repeat work already performed more authoritatively. Rather, a short summary is provided of the most common effects of radiation exposure to the conceptus and the role played by post-conception age at the time of exposure.

Biological effects

The effects of radiation on the developing conceptus are described in the following references:

2. Exposure of the Pregnant Patient to Diagnostic Radiations (Wagner et al. 1997);
3. The Biological Basis of Radiation Protection (Brent 1992; Mossman 1992);
4. Radiobiology for the Radiologist (Hall 1994); and

Many other worthy references exist; these are simply the ones I use most frequently.

The biological effects of radiation exposure to the conceptus are both stochastic and deterministic in nature. Stochastic effects primarily show themselves as an increased risk of developing childhood cancer as a result of the exposure. The risk factor for carcinogenesis from in-utero radiation exposure appears to be about $5 \times 10^{-2}$ person-Sv$^{-1}$ before the age of 14 y (Brent 1992), and a threshold of 0.1 Gy has been noted in experimental animals (NCRP 1998).

Deterministic effects do not seem unique to radiation when compared to other agents and include microcephaly, mental retardation, small birth weight, reduced organ weights, or spontaneous abortion (NCRP 1998). These risks seem especially sensitive to the conceptus’ age at the time of exposure with the most sensitive time being during organogenesis (2–15 wk post-conception (Wagner et al. 1997). Early in this process, damage to a single cell can cause significant problems because each organ has so few cells. Deterministic effects seem to have a threshold at about 5 rads (Brent 1992).

The radiosensitivity of the conceptus is relatively low during the pre-implantation stage, in spite of rapid cell division and relative radiosensitivity of individual cells. However, the ability to repair damage and regenerate lost cells is equally high, and animal studies have not shown long-term effects to be significant. The most likely result of excessive radiation exposure during this stage is spontaneous abortion (miscarriage), which may go unnoticed because of the high background rate (up to 35%; Brent 1999).

Following implantation, the conceptus becomes more sensitive to the effects of ionizing radiation. In fact, risks from radiation exposure to the conceptus seem to be greatest from implantation until about the fifteenth week of pregnancy. In this period, risks seem to be highest between the eighth and fifteenth weeks (Wagner et al. 1997).

DOSE CALCULATIONS

Determining radiation dose to the conceptus is not difficult, provided good references are available for use. In my opinion, using standard, accepted references and methodology is the best way to calculate such doses unless the health physicist has established a high degree of expertise in this area.

The University of Rochester is fortunate to have two certified health physicists currently on staff. For any case involving exposure of the conceptus to diagnostic radiology or nuclear medicine procedures each health physicist independently calculates radiation exposure using separate references. The results are then compared and are reported to the woman’s obstetrician. A brief description of factors to be considered in performing these calculations will be found in the following paragraph. Actual calculation techniques or sample calculations are not included in this paper because they are presented quite clearly in referenced materials.

Radiology procedures

Radiology procedures include x-ray films, computed tomography (CT) scans, and fluoroscopy imaging. Images may be obtained using a number of projections, each with a different abbreviation. These are as follows:
- [AP—Anterior-Posterior] (the beam enters through the patient’s front and exits out his or her back):
- [PA—Posterior-Anterior] (the beam enters through the patient's back and exits through his or her front);
- LAT—Lateral (the beam passes laterally through the patient, from one side to the other);
- Oblique—beam passes through at an angle to the perpendicular;
- Caudal/Cephalic tilt—tube in a PA or AP projection is tilted to project beam towards feet/ head;
- C/Spine (or CS)—cervical (neck) vertebrae are imaged;
- T/Spine (or TS)—thoracic (chest) vertebrae are imaged; and
- LS/Spine (or LS/S)—lumbar and sacral (vertebrae behind the abdomen and pelvis) are imaged.

In general, only x rays, CT scans, and fluoroscopy in the abdominal and pelvic regions will contribute a significant dose to the conceptus. Some procedures, such as barium enemas or barium swallows, will also result in radiation exposure to the conceptus because of subsequent x rays and fluoroscopy time.

The majority of dose to the conceptus is from the primary beam if the uterus is in the field imaged. In addition, scattered radiation from adjacent regions will contribute exposure. Some factors affecting radiation dose to the conceptus for each mode of exposure are summarized in Table 1.

To calculate the radiation exposure, it is first necessary to collect as much relevant information as possible. Every effort should be made to obtain at least the information contained in Table 1. In addition, if your facility has performed exposure measurements on the specific machines used on the pregnant patient, these measurements should be used for exposure calculations because even the best theory is no substitute for actual measurements.

Tables of entrance skin exposure (ESE) can be found in the references mentioned above for many variations of equipment settings. This dose will be attenuated, of course, by passage through the patient to the uterus. The fraction of the ESE dose reaching the conceptus can be determined by using standard conversions, based on the tube potential, the amount of filtration, the size of the patient, the anatomical location of exposure, and other factors. This information, again, is readily available in table form in a number of references.

One other factor must be mentioned with regard to exposure from CT: the effects of multiple slices that image the conceptus. The definition of radiation exposure is, of course, the amount of energy absorbed per unit mass, suggesting that uniform irradiation...
Table 2. Relevant radiological parameters used to determine fetal dose (from an actual case).

<table>
<thead>
<tr>
<th>Projection</th>
<th>No. shots</th>
<th>Tube potential (voltage)</th>
<th>milli-Amp seconds per shot</th>
<th>Tube-to-patient distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>13</td>
<td>109 kVp</td>
<td>20</td>
<td>36'</td>
</tr>
<tr>
<td>LAT</td>
<td>2</td>
<td>90 kVp</td>
<td>20</td>
<td>72'</td>
</tr>
<tr>
<td>PA (spot films)</td>
<td>7</td>
<td>109 kVp</td>
<td>20</td>
<td>36'</td>
</tr>
</tbody>
</table>

Fluoroscopy:
- Beam time: 7 min
- Entrance skin exposure rate: 1.99 R/min (measured)

Table 3. Calculated fetal exposure, based on parameters noted in Table 2. Doses (1) and (2) were calculated independently using different references and methodologies.

<table>
<thead>
<tr>
<th>Source of exposure</th>
<th>Fetal dose—Rad (1)</th>
<th>Fetal dose—Rad (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>1.01</td>
<td>3.04</td>
</tr>
<tr>
<td>LAT</td>
<td>0.037</td>
<td>0.11</td>
</tr>
<tr>
<td>PA</td>
<td>0.545</td>
<td>1.64</td>
</tr>
<tr>
<td>Fluoroscopy</td>
<td>6.28</td>
<td>6.28</td>
</tr>
</tbody>
</table>

| Total fetal dose   | 7.87 Rad            | 11.07 Rad           |

Table 4. Medical recommendations based on calculated exposure summarized in Table 3, from Wagner et al. (1997).

<table>
<thead>
<tr>
<th>Postconception age</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;14 d</td>
<td>No actions recommended</td>
</tr>
<tr>
<td>14–56 d</td>
<td>Termination of pregnancy possibly warranted if other severe risks exist</td>
</tr>
<tr>
<td>57–105 d</td>
<td>Termination of pregnancy possibly warranted if other risks exist</td>
</tr>
<tr>
<td>&gt;105 d</td>
<td>No actions recommended</td>
</tr>
</tbody>
</table>

The most likely source of radiation exposure from injected or orally administered radiopharmaceuticals is exposure from other organs in which the compound may accumulate. These organs include target organs (such as kidneys, lungs, or liver) that are being imaged or waste-collecting organs such as the bladder and bowels in which the compounds may accumulate prior to elimination. The post-conception age of the conceptus is important in determining exposure from these sources because the position of the uterus changes with respect to other organs during the course of any pregnancy. Tables provided in Wagner et al. (1997) and Russell et al. (1997b) summarize the dose conversion factors for a wide variety of radiopharmaceuticals at different post-conception ages.

**Nuclear medicine procedures**

Some patients may receive nuclear medicine procedures not knowing they are pregnant and in spite of administering pre-procedural pregnancy tests. All patients should be asked if they may be pregnant prior to commencing these procedures, but, even so, a pregnancy may be missed due to false negative results, a very early stage pregnancy, or other factors.

Exposure from nuclear medicine studies are, in many ways, simpler to calculate than radiology procedures because there are fewer factors to consider. Specifically, radiation exposure will depend on the amount of radiopharmaceutical administered, the radiation(s) and energy(s) emitted, and the biokinetics of the particular radiopharmaceutical. Most of these factors are obvious and will not be discussed further, but biokinetic effects are not necessarily intuitive and require further discussion.

Although data on the transfer of radiopharmaceuticals across the placenta are limited, there are some data indicating that iodine (often administered as NaI) will cross to the fetus, resulting in thyroid exposure if the thyroid has formed at the time of exposure (Wagner et al. 1997). Other information is available through the Radiation Internal Dose Information Center (RIDIC at Oak Ridge, TN) site at [http://www.ornal.gov/ehsd/doses.htm](http://www.ornal.gov/ehsd/doses.htm), where information on fetal dose is reported from Russell et al. (1997a, b).
the basis for the final report. It is important to remember that we are not physicians, and we cannot give medical advice or recommendations. For this reason, we communicate our results to the physicians involved in each case, including (as appropriate) the woman’s OB/GYN, the radiologist, the attending physician ordering the examination(s), and/or the woman’s primary care physician. The letter contains the following information:

1. A description of events leading to the radiation exposure (i.e., motor vehicle accident);
2. A brief description of the methods used to calculate radiation exposure;
3. A table summarizing relevant exposure data (i.e., number of films, kVp, mAs, etc.);
4. A table summarizing exposure calculations from each source;
5. A brief description of possible effects of radiation exposure;
6. A summary of recommendations from the medical literature for exposure in this range;
7. A photocopy of the relevant page(s) from the literature cited, including full citation information;
8. A table from the medical literature summarizing recommended actions based on radiation exposure and post-conception age;
9. Health physics recommendations (i.e., minimize exposure to ionizing radiation, removal from occupational exposure to ionizing radiation, etc.);
10. An explicit statement that we are not able to provide medical advice, but only to perform the dose calculations and to provide a summary of recommendations from the medical literature; and
11. Contact information in the event the patient or her physician has any additional questions.

The tables noted in points 3, 4, and 8 above will, of course, differ for each patient. An example of each of these is included here, all taken from a recent such patient.

Immediately after completing dose calculations, the woman’s OB/GYN is contacted by telephone, informed of the dose calculations, and a copy of the letter is faxed. A hard copy of the letter is then mailed to the physician with copies sent to the other physicians noted above.

LEGAL CONSIDERATIONS

As is the case in virtually all cases involving exposure to radiation, there are some legal issues that must be considered. As noted above, there is a finite chance that any pregnancy will end in miscarriage or some sort of birth defect, regardless of radiation exposure. This means that there is also a chance of litigation resulting, should this happen to an exposed mother. As health physicists, there is an ethical obligation to perform and report dose calculations as accurately as possible and to report recommendations from the medical literature as accurately. As employees, there is also an obligation to help protect the institution from unreasonable legal action. While the following suggestions are not intended to be comprehensive, they may provide some guidance of issues worth considering so that fulfilling ethical obligations does not result in legal liability to the institution:

- **Work and report within your area of competence:** As mentioned above, a health physicist is not a physician and cannot give medical advice. A health physicist should perform the best dose calculation possible using the best references available and report that information to the physician.
- **Provide accurate dose calculations:** It is absolutely essential that dose calculations be performed as accurately as possible. If possible, they should be checked or repeated. Setting up a spreadsheet may help to ensure consistency, especially if several months may elapse between such calculations.
- **Report all relevant information:** All results should be reported to the patient’s physician if more than one person performed calculations or if two methodologies were used. If all calculational results are not reported, then highest exposure should be the one reported unless these calculations are suspect.
- **Provide ample information:** In addition to a descriptive letter (ours are 2–3 pages in length), enough information should be provided to allow the physician to give informed advice to the patient. This should include a summary of possible radiation effects on the conceptus, a summary of medical recommendations (and their source), and any particulars that might make a case unique. Many physicians have never had to deal with such cases and the immediate reaction of many is to recommend terminating the pregnancy. To overcome this knee-jerk reaction, relevant information should be provided during phone calls and in writing.
- **Be available as a resource:** In addition to everything else, make sure the physician is fully aware that other literature exists to help reach an appropriate decision. Provide contact information, and offer to supply references (we have several papers and books already flagged for easy copying). Make it as simple as possible for the physician to contact you for additional information so that they feel comfortable with their recommendations.
The health physicist’s legal obligation is to perform accurate dose calculations using accepted methodologies and standard references. Once satisfied that the results are as accurate as possible, they must be reported accurately to the physician along with any supplemental relevant information.

CONCLUSION

Virtually all medical centers have programs to identify pregnant patients prior to potential exposure to ionizing radiation. Nonetheless, some pregnant patients will be exposed inadvertently for a variety of reasons. In such instances it is important to collect all the information necessary to calculate radiation dose to the conceptus and to perform those calculations as rapidly and accurately as possible. This information must be conveyed to the woman’s physician along with sufficient additional information to allow the physician to make a reasonable medical recommendation to the patient. By not straying from our areas of competence, reporting all relevant information as accurately as possible, providing guidance as reported in the medical literature, and working in a professional and competent manner, the health physicist and their institution should be protected from legal liability in the event a pregnancy ends unhappily due to “natural” causes.

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REFERENCES


