Conceptus Radiation Dose and Risk From Cardiac Catheter Ablation Procedures

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Background—The aim of the current study was to estimate the conceptus radiation dose and risk associated with fluoroscopic imaging during a catheter ablation procedure for supraventricular tachycardia performed on the expectant mother.

Methods and Results—Exposure parameters and fluoroscopy times for each projection of the cardiac ablation procedure performed in 20 female patients of childbearing age were recorded. Radiation doses for a potential conceptus were estimated by using dose data obtained in anthropomorphic phantoms simulating pregnancy at the first, second, and third trimesters. Dose measurements were carried out using thermoluminescent dosimeters. For a typical examination, the average radiation dose to the conceptus was \(1\) mGy in all periods of gestation. Average excess fatal cancer was \(14.5/10^6\) unborn children irradiated during the first postconception weeks. Corresponding values for the second and third trimesters were 30 and 55.7/10^6, respectively. The risk for hereditary effects in future generations was 1.5/10^6 cases for conceptus irradiation during the first postconception weeks. Corresponding values for the second and third trimesters were 3.0 and 5.6/10^6, respectively. Formulas and dose data are presented for estimating the conceptus risk from any technique and x-ray system used for catheter ablation procedures.

Conclusions—A typical catheter ablation procedure results in a very small increase in risk of harmful effects to the conceptus. However, estimation of conceptus dose from catheter ablation procedures is always needed to assess the risk to the individual developing in utero. (*Circulation.* 2001;104:893-897.)

Key Words: catheter ablation ■ pregnancy ■ imaging ■ radiography ■ tachycardia

Compared with several other radiographic studies, relatively high doses of radiation are delivered with cardiac catheter ablation procedures. High doses result from the prolonged fluoroscopy time often required for these studies.1–3 The majority of patients who undergo catheter ablation procedures are young, with a mean age of \(\approx 36\) years.4 Despite careful precautions, there will always be a few cases of catheter ablation procedures carried out in female patients of childbearing age when, during the first postconception weeks, a conceptus will be irradiated accidentally. Cardiologists and radiation protection experts are then requested to estimate the dose and potential risk to the conceptus. The estimation of dose to the unborn child is also necessary for a pregnant woman for whom a catheter ablation procedure is considered to be beneficial. Lindsay et al5 suggested that pregnant women should not undergo an ablation procedure unless their arrhythmias are life-threatening and are refractory to drug therapy that can be given safely during pregnancy. X-ray examinations of pregnant women can be carried out only when there is sufficient reason to believe that the benefit exceeds the known risks. To the best of our knowledge, there is no reported experience regarding conceptus radiation doses and risks resulting from fluoroscopic imaging during catheter ablation studies. Kovoor et al4 estimated the dose to the ovaries during catheter ablation. They reported doses of \(<0.05\) mGy, on the assumption that the estimated dose to the ovary would be the same as that to the uterus during the early postconception weeks.

In the current study, our objective was to quantify the radiation risks to the conceptus that are associated with catheter ablation for supraventricular tachycardia performed on the mother. To accomplish this goal, a simple method of estimating conceptus dose during catheter ablation procedures was developed.

Methods

Patient Study
The patient population included 20 female patients of childbearing age (mean, 28.2±5.0 years; range, 20 to 38 years). Each patient gave informed consent for electrophysiological study and catheter ablation for supraventricular tachycardia. Twelve patients suffered from atrioventricular nodal reentrant tachycardia and 8 from Wolf-
Pregnancy Simulation
An adult anthropomorphic Rando phantom (Alderson Research Laboratories) consisting of 36 numbered 2.5-cm-thick transverse slices was used in the current study. The Rando phantom represents an average person of 1.73 m height and 73.5 kg weight and may represent pregnancy at the early postconception weeks. To simulate pregnancy at the second and third trimesters, the phantom was modified by adding rings constructed from Lucite. Seven 2.5-cm-thick rings were fitted around sections 25 to 31 to simulate the abdomen of a pregnant woman at the second trimester. Pregnancy during the third trimester was simulated by adding ten 2.5-cm-thick rings to sections 22 to 31. Each Rando phantom section and each ring contained holes that allowed thermoluminescent dosimeter (TLD) positioning. Details of the modified phantom have been described in an earlier publication.6

X-Ray Fluoroscopy System
All studies were carried out using a constant-potential Philips BV 300 R2 C-arm fluoroscopy unit (Philips Medical Systems). This unit consists of an undercouch x-ray tube and an overcouch image intensifier with the ability of last-image hold. Continuous fluoroscopy mode was used. The focus-to-image intensifier distance was 100 cm and the input field size was 23 cm. X-ray tube potential and current were selected by using the automatic brightness control. The fluoroscopy system was assessed before conceptus dose measurements to determine its accuracy, reproducibility, output, and half-value layer at a range of tube voltages. Output measurements of the x-ray tube used for fluoroscopy were performed in air. A recently calibrated ionization chamber connected to an MDH 2025 AC radiation monitor (Radcal) was used for this purpose. The distance between the ionization chamber and the x-ray-tube focus was 70 cm. The x-ray-tube output was 1.29, 1.34, 1.59, 1.66, and 2.39 mGy (mA × min) for tube voltages of 65, 67, 70, 71, 75, and 80 kVp, respectively. The measured x-ray-beam half-value layer was 4.7 mm aluminum at 70 kVp. This results in a total filtration of 9.0 mm in aluminum. Automatic brightness control was used, which resulted in a tube potential of 65 to 72 kVp and tube current of 2.01 to 2.64 mA.

Fluoroscopic Imaging During Ablation Procedures
At the beginning of the procedure, the electrode catheters are inserted and advanced from the groin to the heart under fluoroscopic control for the atrium was 35 seconds (see Results). To improve the accuracy of fluoroscopic imaging during the ablation procedure was performed with the Rando phantom in accordance with the protocol presented in Table 1.

Conceptus Dose and Risk Estimation
Dose measurements were carried out by using CaF₂ chips (TLD-200, Harshaw). Entrance surface dose (ESD) was measured with a grid of 60 evenly spaced TLD crystals. Depth doses were assessed by using measurements of the TLD crystals placed in the holes of the phantom. Two crystals were placed in each position inside the phantom to estimate the mean value of the dose. Twelve TLDs were placed at slices 29 and 30, which correspond to the location of the embryo at the first trimester.7 One hundred twelve and 180 TLDs were placed at slices 25 to 31 and 22 to 31, respectively, corresponding to embryo locations during the second and third trimesters. The conceptus dose at the gestational period j (j = 1 for the first, 2 for the second, and 3 for the third trimester) for an ablation procedure carried out in a x-ray system S may be calculated by using the formula (Equation 1)

\[
D_{\text{conceptus}} = \sum_{i=1}^{4} \left( \frac{O_{i}}{7} \right) \left( \frac{mA_{i}}{mA} \right) \left( \frac{t_{i}}{SSD} \right) \left( \frac{SSD_{S}}{SSD} \right) D_{i}
\]

where \(i\) is the projection taken during the cardiac ablation procedure (\(i = 1, 2, 3,\) and 4 for the GHPA, PA, LAO, and RAO projections of the heart, respectively); \(O_{i}\) is the output of the system \(S\) at 70 cm, estimated at the mean kVp set for the projection \(i\); \(mA_{i}\), and SSD\(_{i}\) are the tube current, fluoroscopy time, and source-to-surface distance, respectively, used for the projection \(i\) taken in the x-ray system \(S\); \(O\) is the output of the x-ray tube of the system used in the current study estimated at the kVp set for projection \(i\); mA and SSD are the tube current and source-to-surface distance, respectively, used for projection \(i\) taken in the system used in the current study; and \(D_{i}\) is the dose per minute of fluoroscopy for the projection \(i\) estimated in the current study.

Risks were estimated by using the conceptus dose and the National Council on Radiation Protection and Measurements risk estimates.8 Specifically, a probability coefficient for childhood cancer after in utero exposure of 10⁻⁵/Gy was used. The coefficient for induction of hereditary effects was taken as 10⁻²/Gy.

Effect of External Shielding
To investigate the effect of external shielding on conceptus dose, additional dose measurements were carried out with the abdomen and pelvis of the phantom shielded with lead aprons of 0.5-mm-lead thickness equivalence. Doses per minute of fluoroscopy during the

<table>
<thead>
<tr>
<th>Projection</th>
<th>Tube Voltage, kVp</th>
<th>Tube Current, mA</th>
<th>Fluoroscopy Time, min</th>
<th>SSD, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>First trimester</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>GHPA</td>
<td>70²</td>
<td>2.5†</td>
<td>0.58</td>
<td>55</td>
</tr>
<tr>
<td>PA</td>
<td>67</td>
<td>2.3</td>
<td>20</td>
<td>64</td>
</tr>
<tr>
<td>45° LAO</td>
<td>70</td>
<td>2.6</td>
<td>20</td>
<td>62</td>
</tr>
<tr>
<td>25° RAO</td>
<td>65</td>
<td>2.1</td>
<td>20</td>
<td>72</td>
</tr>
<tr>
<td>Second trimester</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>GHPA</td>
<td>75‡</td>
<td>2.7§</td>
<td>0.58</td>
<td>55</td>
</tr>
<tr>
<td>PA</td>
<td>67</td>
<td>2.4</td>
<td>20</td>
<td>64</td>
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<tr>
<td>45° LAO</td>
<td>70</td>
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<tr>
<td>25° RAO</td>
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<tr>
<td>Third trimester</td>
<td></td>
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<td></td>
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<tr>
<td>GHPA</td>
<td>80¶</td>
<td>2.8#</td>
<td>0.58</td>
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<tr>
<td>PA</td>
<td>67</td>
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<td>2.0</td>
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<td>72</td>
</tr>
</tbody>
</table>

* kVp values ranged from 69 to 71.
† mA values ranged from 2.4 to 2.6.
‡ kVp values ranged from 68 to 82.
§ mA values ranged from 2.5 to 2.9.
¶ kVp values ranged from 70 to 90.
# mA values ranged from 2.5 to 3.0.
first, second, and third trimesters were estimated for PA, LAO, and RAO projections of the heart. The pelvis was not shielded during the GHPA phase of the study because the apron would cover the area being imaged. The difference between conceptus dose with and without shielding was expressed as a percentage of the conceptus dose without shielding. Conceptus doses were estimated by the mean fluoroscopy time for the projections taken during the ablation procedures carried out in the patients.

Statistical Analysis
Data concerning exposure parameters of the fluoroscopic imaging performed in patients were expressed as the mean±SD. The effect of the distance between a section of the phantom simulating pregnancy and the center of the x-ray field on dose measured in that section was estimated by linear regression.

Results
Phantom Study

Data for the Estimation of Conceptus Dose During the First Trimester
Table 2 shows the depth dose data per minute of fluoroscopy for the GHPA exposure and the PA, LAO, and RAO projections of the heart measured in sections 29 and 30 of the Rando phantom.

Data for the Estimation of Conceptus Dose During the Second and Third Trimesters
The average ESD rate was 4.5 mGy/min for the PA projection, 4.7 mGy/min for the LAO projection, and 2.7 mGy for the RAO projection of the heart. The natural logarithm of the average radiation dose estimated in a section of the phantom simulating pregnancy, normalized to ESD, as a function of the distance between the section and the center of the radiation field was plotted for PA, LAO, and RAO projections of the heart for both the second and third trimesters. The regression equations and the corresponding coefficients of determination are given in Table 3. The average conceptus dose per minute of fluoroscopy may be calculated by using the formula (Equation 2)

\[
D_i = \frac{(ESD)_i}{20 \times 100} \left( \frac{e^b}{(x_2 - x_1)} \right)^{\sum_{j=2}^{3} \left( e^{ax_j} \right)}
\]

where \(j=2, 3\); \(i=2, 3\); \(a\) and \(b\) are the slope and \(y\) intercept, respectively, of the regression line corresponding to projection \(i\); ESD\(_i\) is the ESD for projection \(i\); \(x_1\) is the distance between the upper boundary of the fetus, ie, the boundary nearest to the head of the pregnant woman, and the center of the heart; and \(x_3\) is the distance between the lower boundary of the fetus and the center of the heart. In the modified Rando phantom, \(x_1=23.75\) cm and \(x_2=38.75\) cm for the second trimester and \(x_1=16.25\) cm and \(x_2=38.75\) cm for the third trimester. The average doses per minute of fluoroscopy per projection measured by TLD crystals positioned in the phantoms representing pregnancy during the second and third trimesters are shown in Table 4.

Patient Study
The ablation procedure was considered successful in 95% of the population studied. Table 5 shows the exposure parameters and fluoroscopy time for each projection of the catheter ablation procedure carried out in the 20 female patients who participated in the current study. An ablation procedure requiring 0.58, 23, 5.3, and 10.2 minutes for GHPA, PA, RAO, and LAO exposures, respectively, was considered to be typical for an examination carried out in a female patient of childbearing age. The estimated doses at various depths and the corresponding mean magnitude of the risk of childhood cancer and hereditary effects for a potential conceptus during the first postconception weeks are shown in Table 6. The Figure shows the contribution of each of the 4 exposures on the total conceptus dose, with the assumption that the conceptus is located 8.5 cm below the anterior surface of the mother. Table 7 shows the conceptus dose during the second and third trimesters. Experiments were performed to investigate the effect of angulation on conceptus dose measurements. The deviation in conceptus dose was <5% when the angle of incidence was varied by ±10°. The conceptus dose with lead shielding was lower than that without lead shielding, the difference being <3% for all periods of gestation.

Discussion
A high incidence of cardiac arrhythmias has been demonstrated in pregnant women with and without heart disease. Although treatment of tachycardias is usually possible with antiarrhythmic medications, it is currently recognized that the
benefit gained with ablation is superior to that achieved through medical therapy. Reported cases show that occasionally, catheter ablation can be advantageous for the pregnant patient. Dominguez et al. performed a successful ablation of a right posteroseptal accessory pathway in a 20-weeks-pregnant patient. They concluded that cardiac ablation is an alternative and safer treatment in those cases in which the tachyarrhythmias compromise the hemodynamic state during pregnancy. Gras et al. reported the case of ablation of atrioventricular conduction in a 5-months-pregnant woman who had hypertrophic cardiomyopathy. A pacemaker was implanted during the same procedure. The patient delivered a healthy child at 8 months’ gestation.

Recent technological advancements have led to a significant increase in the number of ablation procedures performed annually in the United States. In cases of accidental irradiation of the unborn child, the estimation of conceptus dose is also necessary to evaluate the risks from a catheter ablation procedure, so that decisions can be made concerning management of the gestation. Studies have been published regarding doses and risks to a conceptus resulting from several x-ray examinations. However, no data have been found in the literature on the level of radiation dose to a conceptus during cardiac catheter ablation procedures.

Biological Effects of Ionizing Radiation in Unborn Children

It is well known that when the dose to the conceptus is < 50 mGy, there is no harm from deterministic effects, and the risk of stochastic effects is 10^−5/Gy for cancer induction and 10^−7/Gy for induction of hereditary effects. The results of the current study show that deterministic effects are very unlikely to be caused by fluoroscopic imaging during a catheter ablation procedure. The conceptus risks of both stochastic effects due to a typical catheter cardiac ablation procedure were estimated. The risk of fatal childhood cancer ranged from 10.2×10^−7 to 20.4×10^−8 during the first postconception weeks. In comparison with the natural prevalence of fatal childhood cancer, estimated to be 769×10^−6, the increase in risk associated with the exposure in utero due to a typical cardiac ablation procedure is very small. The risk for hereditary effects in future generations ranged from 1.0×10^−6 to 2.0×10^−6 for a conceptus during the first postconception weeks, a value that is considerably smaller compared with the current incidence of serious birth defects, estimated to be 6%. The risk of childhood cancer was 30×10^−6 and the risk of genetic effects was 3.0×10^−6 for the conceptus during the second trimester. Corresponding values for the third trimester were 55.7×10^−6 and 5.6×10^−6. It should be stressed that the range of techniques and x-ray systems used for catheter ablation procedures is quite varied. This variation may introduce large ranges of potential conceptus doses and risks. Prenatal doses from cardiac ablation procedures present an increased risk of childhood cancer and genetic effects over the background incidence of these entities. Although the presented data show that these risks are low, it is worth noting that the biological effects on the conceptus of low-dose ionizing radiation is an evolving field in which much data have been revised over the last decade. Therefore, pregnant women should undergo an ablation procedure only in case of emergency.

Accuracy of Radiation Dose Estimation

Inaccuracies in the methods developed for the direct determination of radiation dose to the conceptus may be due to errors existing in TLD and abnormal patient size. To reduce the overall uncertainty on a dosimeter reading, the use of individual sensitivity correction factors was applied. Significant variations in conceptus dose may occur depending on

| TABLE 5. Tube Potential, Tube Current, and Fluoroscopy Time for Each Projection of the Catheter Ablation Procedures Performed in 20 Female Patients |
| --- | --- | --- | --- |
| Fluoroscopic Exposure | kVp | mA | Time, min |
| GHPA | 71±5 | 2.6±0.5 | 0.58±0.4 |
| PA | 67±3 | 2.4±0.3 | 23.0±7.6 |
| RA0 | 67±5 | 2.2±0.4 | 5.3±2.8 |
| LAO | 70±4 | 2.6±0.5 | 10.2±4.3 |

| TABLE 6. Conceptus Doses and Risks From a Typical Catheter Ablation Procedure During the First Postconception Weeks |
| --- | --- | --- | --- |
| Depth, cm | Dose, mGy×10^−3 | Risk×10^−6 |
| | Carcinogenesis | Genetic Effects |
| 5.5 | 101.8 | 10.2 | 1.0 |
| 8.5 | 145.1 | 14.5 | 1.5 |
| 11.5 | 204.3 | 20.4 | 2.0 |

| TABLE 7. Conceptus Doses and Risks From a Typical Catheter Ablation Procedure During the Second and Third Trimesters of Gestation |
| --- | --- | --- | --- |
| Trimester | Dose, mGy×10^−3 | Carcinogenesis | Genetic Effects |
| | | | |
| Second | 300 | 30 | 3.0 |
| Third | 557 | 55.7 | 5.6 |
patient size. Because the amount of tissue is greater in patients of larger girth compared with the Rando phantom, obese patients may require considerably increased tube potential (kVp) and current (mA). For this reason, obese women will absorb more radiation dose than will thin ones. An advantage of the method developed in this study is that it is applicable to patients whose sizes differ substantially from the phantom, because it takes into account variations in tube current (Equation 1).

In the x-ray unit used in the current study and in most fluoroscopy units, the x-ray beam is emitted continuously. However, pulse fluoroscopic systems are also in use in several institutions. These systems depict anatomy as a sequence of frames acquired in rapid succession by using radiation pulses. Pulsed fluoroscopy decreases the radiation exposure time and dose. Equation 1 is applicable to those systems as well. Estimating a conceptus dose from a pulsed fluoroscopic system requires the output of the x-ray tube to be determined in pulsed mode, total fluoroscopy time, kVp, mA, and SSD for the projections involved in the catheter ablation procedure.

Minimization of Conceptus Radiation Dose

The Figure shows that >50% of the total radiation dose to the conceptus is due to the GHPA exposure. Insertion of the catheter by the subclavian route instead of the femoral eliminates direct conceptus irradiation. A previous study has shown that conceptus depth is strongly influenced by the status of the maternal bladder. The mean conceptus previod and postvoid abdomen depths were 8.4 and 5.8 cm, respectively, as estimated from a group of 73 pregnant women at gestational ages of 5 to 13 weeks. Table 2 shows that conceptus dose rate is dependent on conceptus depth during the first trimester: the shorter the conceptus distance from the anterior maternal surface, the lower the dose rate to the unborn child. Therefore, if it becomes necessary for a pregnant woman to undergo a catheter ablation procedure during the first trimester, fluoroscopic imaging with an empty bladder delivers the lowest absorbed dose to the conceptus. Contrary to popular belief, external shielding of the pelvis of the patient is of limited value. The radiation dose absorbed by the conceptus without shielding was found to be <3% higher than that with external shielding for all periods of gestation. Obviously, most of the conceptus dose is attributable to scatter from the thorax of the mother.

References

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