Risk to Patients From Radiation Associated With Radiofrequency Ablation for Supraventricular Tachycardia

Pramesh Kovoor, MBBS, MD, FRACP, PhD; Michelle Ricciardello, MSc; Lee Collins, MSc, FACPSEM; John B. Uther, MBBS, MD, FRACP; David L. Ross, MBBS, FRACP

Background—Radiofrequency ablation may be associated with prolonged fluoroscopy times. Previous studies have calculated radiation risks by measuring the radiation dose at a limited number (6) of body sites. This is an inherently inaccurate measure. Our study aimed to quantify more precisely patient-related radiation risks associated with radiofrequency ablation for supraventricular tachycardia.

Methods and Results—Nine female patients having radiofrequency ablation for supraventricular tachycardia were studied. The radiation dose was determined at 41 body sites in each patient with the use of thermoluminescent dosimeters and was correlated with that measured simultaneously with a Diamentor dose-area product meter. The estimated mean organ doses (mGy) per 60 minutes of fluoroscopy were: lungs 30.8; bone marrow 4.3; left breast 5.1; right breast 3.5; and thyroid 2.4. From the average organ doses, the estimated mean total lifetime excess risk of a fatal malignancy was 294 per million cases (0.03%) per 60 minutes of fluoroscopy. The risk calculation from the Diamentor dose-area product and thermoluminescent dosimeters were similar, suggesting that radiation dose was measured accurately. The estimated risk of radiation-induced malignancy increased with increasing body mass index ($P = 0.03$).

Conclusions—Prolonged fluoroscopy during radiofrequency ablation may potentially cause a small increase in the lifetime risk of fatal malignancy, with lung malignancy being most likely. This risk is small only with the use of techniques and x-ray equipment optimized to keep radiation as low as possible. The risk is increased in obese patients. (Circulation. 1998;98:1534-1540.)

Key Words: radiation risks ■ RF ablation ■ fluoroscopy

Radiofrequency ablation has become the preferred method of treatment of supraventricular tachycardia. The success rate has been >85% at the first attempt, with a low incidence of complications. This procedure has replaced surgery as the preferred method for cure of these conditions. Prolonged fluoroscopy (66±37 minutes) is often required for these procedures, especially in patients with multiple atrioventricular connections. The majority of patients who undergo these procedures are young, with a mean age of about 36 years. Predisposition to late malignancies as a sequel to this radiation exposure is therefore a source of concern. Calkins et al quantitated the radiation exposure during radiofrequency catheter ablation of accessory atrioventricular connections. Kovoor et al assessed radiation exposure during radiofrequency catheter ablation of atrioventricular junctional reentry as well as accessory atrioventricular connections. The study performed by Calkins et al estimated the subsequent risk of a fatal malignancy for the irradiated patient to be approximately 0.7 per 1000 patients or 1 per 1000 patients per 1 hour of fluoroscopy. In that study and in the study by Kovoor et al, there was a large variation in the radiation doses measured by the thermoluminescent dosimeters (TLDs) and poor correlation with fluoroscopy times. This was most likely due to an insufficient number of TLDs to ensure that the x-ray beam always intercepted dosimeters in the array as the beam is moved during the study. The mean area of the x-ray beam at the skin surface was 100±10 cm², whereas the mean area of the patient’s back over which the beam could possibly move was 720 cm². Both the previously discussed studies used TLDs at only 5 to 6 sites on the patients.

The purpose of this study was to determine more accurately the dose of radiation delivered to patients during radiofrequency ablation for supraventricular tachycardia and assess the possible risk of malignancy from the exposure. We appreciated that the amount of radiation the patient is exposed to would depend on the fluoroscopy equipment used and how carefully the operators strove during the procedure to reduce radiation exposure to the patient. The use of large image intensifier fields and judicious use of collimation would obviously reduce radiation exposure to the patient considerably. We aimed at the outset to use techniques and x-ray equipment optimized for the lowest possible radiation dose commensurate with acceptable image quality.
Methods
Radiation exposure was determined in 9 female patients having radiofrequency ablation for supraventricular tachycardia. Informed consent was obtained from all patients. Only women were studied to allow accurate quantitation of female breast irradiation. The patient characteristics are given in Table 1. All patients had symptomatic supraventricular tachycardia.

Measurement of Radiation Dose by Thermoluminescent Dosimetry
Radiation dose was determined at 41 body sites in each patient with the use of TLDs (Teledyne TLD1000 LiF-N chips, 3 mm square). The TLDs were calibrated at the mean kVp used for each patient, with an mdh Radcal model 2025 ionizing chamber dosimetry system. The TLDs were positioned on the patient before commencement of the procedure. Radiation to the thorax was measured with a grid of 30 evenly spaced (6 cm) TLDs positioned on the posterior aspect of the thorax (Figure 1), covering a total area of 720 cm². The positioning of these TLDs was guided by a marked plastic sheet template so as to have uniform positions and distribution in each patient. The C8 spinous process was used as a reference point for placement of the template. Doses from the 20 highest-reading TLDs were averaged.

Radiation to the breasts was measured with 9 TLDs (Figure 2). Of those 9, 4 TLDs were positioned over each breast (lateral, medial, inferior, and just above the nipple) and 1 TLD was placed over the xiphisternum (Figure 2). In addition, radiation to the thyroid was estimated with 1 TLD positioned anterior and 1 posterior to the thyroid (Figures 1 and 2).

Measurement of Radiation Dose With Dose-Area Product Meter
The dose-area product of the total output of the x-ray tube was measured simultaneously with a PTW Diamentor-D dose-area product meter. The ion chamber was positioned on the x-ray tube before commencement of the procedure. The Diamentor was calibrated in a manner previously described.11

Radiofrequency Ablation
The procedures were performed by 2 experienced electrophysiologists, each of whom had performed >100 radiofrequency ablations before the study. All procedures were performed with patients in the postabsorbptive state during sedation with continuous infusion of midazolam and fentanyl. Quadrupolar catheters were inserted through the left femoral vein and positioned in the high right atrium and right ventricular apex. A tripolar catheter was inserted through the left femoral vein to record the His bundle. A decapolar catheter was inserted through the right subclavian vein into the coronary sinus. A detailed diagnostic study was performed in all patients before the ablation to determine the baseline electrophysiological properties, study the inducibility of the tachyarrhythmias, and map in detail the locations of the accessory pathway or reentrant circuits.

A Toshiba single-phase, half-wave, rectified C-arm fluoroscopy system (model KXO-650) was used to position the catheters. The

Figure 1. Median (interquartile range) skin absorbed dose of radiation (mGy) per 60 minutes of fluoroscopy measured from 31 TLDs positioned on posterior aspect of the patient. Grid of 30 TLDs was positioned over posterior thorax. One TLD was positioned posterior to thyroid at level of C8 spinous process.

Figure 2. Median (interquartile range) skin absorbed dose of radiation (mGy) per 60 minutes of fluoroscopy measured from 10 TLDs positioned on anterior aspect of the patient. Four TLDs were positioned over each breast (lateral, medial, inferior, and just above the nipple) and 1 thermoluminescent dosimeter was placed over the xiphisternum. One thermoluminescent dosimeter was positioned anterior to the thyroid.

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<th>TABLE 1. Patient and Procedure Characteristics</th>
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Fluoroscopy time, diagnostic indicates duration of fluoroscopy for the initial diagnostic aspect of the procedure; Fluoroscopy time, total, duration of fluoroscopy for the total procedure; and RF applications, number of deliveries of radiofrequency energy.

Values are mean±SD (range) or numbers (%).
x-ray tube was located under the table and the image intensifier above the table. The system used continuous fluoroscopy, not pulsed fluoroscopy.

The measured x-ray beam half-value layer was 5.95 mm aluminum at 96 kV and 6.2 mm aluminum at 105 kVp. This was equivalent to 8 mm aluminum total filtration, including the table filtration effect, calculated for a single-phase unit with 12 degree target angle. The image intensifier had a fixed grid with grid ratio of 12:1 and a focal length of 90 cm. The image intensifier had 3 field sizes of 23, 17, and 11 cm. The 23-cm field was used in most cases. Kilovoltage was determined by an automatic brightness control for manually chosen tube currents (usually 0.5 to 1.0 mA, but occasionally up to 2 mA for very obese patients). The tube current was kept at the lowest possible setting that gave a clinically satisfactory image. Cinefluorography was not used in any patient. Collimation was used routinely.

Positioning of the catheters at the right atrium, right ventricle, and His bundle was performed with fluoroscopic imaging in the postero-anterior position. Coronary sinus catheterization was usually performed in the left anterior oblique position. Once the tachycardia mechanism was confirmed, a 7F quadrupolar steerable ablation catheter with a 4-mm distal electrode (Mansfield/Webster) was introduced through the right femoral vein or artery, depending on the location of the abnormal pathway targeted for ablation. Some right free wall accessory pathways required insertion of the ablation catheter from the subclavian or internal jugular veins. For positioning of the ablation catheter in atrioventricular junctional reentry tachycardia cases, fluoroscopic imaging was predominantly in the right anterior oblique view. For right free wall accessory pathways the left anterior oblique view was mainly used. For other types of arrhythmias the positioning of the image intensifier was variable.

Radiofrequency energy was delivered with a Zencor MF1 bipolar coagulator. The energy was delivered in unipolar fashion between the 4-mm catheter-tip electrode and a Valleylab Poly Hesive return electrode.

Calculation of Radiation Risks

Risks were calculated by 2 independent methods, using the measured radiation absorbed dose from TLD and also the dose area product from the Diamentor. International Council for Radiation Protection (ICRP) 60 (1990) risk estimates were applied to estimated absorbed organ doses. These risk estimates (or probability of fatal cancer) were derived from a variety of sources, but particularly the 1988 UNSCEAR report and the BEIR V report. From this data, a best estimate of risk was selected for ICRP 60. While the accuracy of the risk estimates could be challenged, they remain the best values available.

The ICRP population-averaged fatal cancer probability coefficient of 0.05 Sv was used. However, it would be more accurate to use age-related coefficients for estimation of risk when the age range is known to be small. For the purposes of comparison with other studies in which the age range is variable, we have chosen to use the population-averaged probability coefficients. We do, however, realize that the relatively young age of the patients will increase the risk of breast cancer in comparison to the population average figure and also that thyroid cancer is twice as prevalent in women as in men.

Calculation of Excess Risk From Absorbed Dose From TLD

For the breast, the average measured skin dose for the 9 TLDs was used. The anterior measured skin dose was used for the thyroid. For the lung, ovaries, and bone marrow, the organ doses were calculated by a freely available computer program from the average skin absorbed dose measured for 20 sites (Figure 1, rows 2 to 5) over an area of 24 by 18 cm, centered on the midline and PA chest projection. The average of 20 sites was used because the x-ray field is moved and angulated frequently during a procedure. As a result, some TLDs could be out of the x-ray field for part of the time or at varying distances from the x-ray tube (causing inverse square law effects). To calculate the total risk of excess fatal cancer, the mean absorbed dose to the critical organs in the primary beam (lungs, bone marrow, and breasts) and to the thyroid and ovaries was multiplied by the appropriate risk factors from ICRP 60. The risk factors used were: lungs 8.5; bone marrow 5; breasts 2; and thyroid 0.8 fatal cancers per mGy organ dose per million cases. This of course assumes that the only significant radiation-related cancer risks will be to these organs.

Calculation of Excess Risks From Diamentor Dose

The risk of fatal cancer of all types was also determined from the dose-area product. The dose-area product data was converted to effective dose with the approach of LeHeron, with the use of a commercially available computer program (XDOSE)(1). The effective dose was then multiplied by the probability coefficient for fatal cancer. This program assumes the patient is an adult of 70 kg mass and 174 cm height (body mass index = 23.1).

Calculation of Hereditary Effects

The risk of hereditary effects was obtained by multiplying the average dose to the ovaries by the probability of severe hereditary effects (10 per mSv per million cases). The dose to the ovaries was calculated by a computer program, using the average skin entrance exposure from 20 TLD sites (Figure 1, rows 2 to 5).

Statistical Analysis

The statistical package SPSS was used. Spearman rank correlation coefficients were used to examine the associations between the different variables of interest.

Results

The details of fluoroscopy time are summarized in Table 1. The median skin absorbed doses measured by the 41 TLDs are summarized in Figures 1 and 2. The dose of radiation to individual organs and the estimated risk of malignancy are summarized in Table 2. The estimated mean total lifetime risk of fatal malignancy from 60 minutes of fluoroscopy for radiofrequency ablation measured from the average organ doses (measured using TLDs) was 294 excess cases of fatal malignancy per million patients or 0.03% excess cases of fatal malignancy. From the dose-area product measured with the Diamentor, the estimated mean total lifetime excess risk of fatal malignancy was 317 per million cases per 60 minutes of fluoroscopy (mean effective dose = 6.34 mSv). The risk of severe hereditary effects was less than 1 per million cases for 60 minutes of fluoroscopy.
There was a good correlation between the risk of malignancy calculated with TLDs and that calculated with the Diamentor (Figure 3). The risk of a fatal malignancy increased with increase of body mass index (Figure 4). There was good correlation between the mean absorbed dose measured by the 8 TLDs positioned directly over the breasts and the single thermoluminescent dosimeter positioned over the xiphisternum (Figure 5). The estimated number of excess cases of fatal breast malignancy was 8.6 ± 3.8 per million patients per 60 minutes of fluoroscopy when the radiation dose to the breast was calculated from the mean of the 8 TLDs directly over the breasts and assuming that this figure is closely related to the mean organ absorbed dose. Given that the TLD positions ranged from nipple to chest wall, the approximation is reasonable.

Discussion
This study provides a detailed assessment of the radiation exposure to the patients and the resultant risks associated with radiofrequency ablation for supraventricular tachycardia. We were able to demonstrate good agreement between 2 independent methods of radiation measurement (that is, TLD and dose-area product methods) indicating that the results are likely to be reliable. The study confirms that use of fluoroscopy during catheter radiofrequency ablation is likely to result in a small increase in the lifetime risk of a fatal malignancy and that the most likely malignancy will be lung.

Biological Effects of Radiation
The biological effects of radiation can be both somatic (those occurring in the exposed person) or hereditary. Somatic effects are either stochastic (where, according to the currently accepted linear no-threshold hypothesis any exposure carries a risk) or deterministic (where there is a threshold dose for the effect to occur and below which no damage occurs). Stochastic effects include malignancies, especially leukemia. Deterministic effects include cataract formation and some developmental abnormalities of children exposed in utero. Hereditary effects are those that affect the germ cells and may be evident in the progeny.

In this study we estimated the stochastic somatic effects as well as the hereditary effects of radiation to the patient. The overall increase of fatal malignancy was found to be small (0.03% for 60 minutes of fluoroscopy). The most likely malignancy is lung, the organ exposed to the maximum amount of radiation. Lung carcinoma is 20 times more likely and leukemia is 1.7 times more likely than breast carcinoma from 60 minutes of fluoroscopy. The possibility of fatal thyroid carcinoma is only 0.0002%, since this is often a survivable disease. In the calculations of risk, there was no consideration made of a dose/dose rate effectiveness factor because of the low dose rate and the relatively low total doses.

Severe radiation induced skin injuries to patients resulting from prolonged, fluoroscopically-guided, invasive procedures such as percutaneous transluminal coronary angioplasty and radiofrequency catheter ablation have been reported. Radiation induced skin injury did not occur in any patient in our study.

The risk of severe hereditary effects was found to be less than 1 per million cases for 60 minutes of fluoroscopy. This is much less than the risk of 20 per million reported by Calkins et al in female patients.

Accuracy of Radiation Risk Measurement
During electrophysiological studies, a variety of fluoroscopy views are used. This results in considerable variation in the areas affected by radiation. To allow for this and to enable accurate measurement of radiation to the patient, the TLDs were positioned at a large number (41) of body sites. The maximum radiation to the thorax was detected by the TLDs in the center (Figure 1), suggesting that the radiation was well bracketed by the TLDs. The risk estimates derived from the Diamentor dose-area product and TLDs were similar, suggesting that the radiation dose was measured reliably (Figure

**Figure 3.** Correlation between the excess risk of fatal malignancy per million cases per 60 minutes of fluoroscopy as measured with data from TLDs versus that measured with dose-area product meter.

**Figure 4.** Correlation between excess risk of fatal malignancy per million cases per 60 minutes of fluoroscopy and body mass index.

**Figure 5.** Correlation between mean radiation (mGy) measured from directly over breasts with 8 TLDs versus that measured with 1 TLD over the xiphisternum.
Increased Risk of Malignancy Associated With Obesity

As would be expected, the estimated risk of malignancy increased with increasing body mass index of the patient (Figure 4) because of the increase in radiation necessary to obtain satisfactory images in obese patients. Body mass index alone, however, is not necessarily a good measure of body thickness in the region of the x-ray beam.

The computer programs used to convert Diamentor and TLD data to effective and organ dose assume a particular body size (70 kg and 174 cm height)—so-called “standard man.” Larger patients may have doses underestimated, and similarly, larger patients may have doses overestimated. Because the average patient mass and height in this study were not greatly removed from standard man, dosimetry errors will be minimal.

Reliability of Measuring Radiation to Breasts With Single Thermoluminescent Dosimeter Over the Xiphisternum

Other studies that have assessed radiation to patients associated with cardiac catheterization have used one TLD over the xiphisternum to determine the radiation to the breasts. In our study, we assessed the reliability of measuring radiation to the female breasts by using both a single TLD over the xiphisternum and 4 TLDs over each breast. There was a good correlation between the absorbed dose detected by the single xiphisternal TLD and the average of multiple breast TLDs. Measurement of radiation dose by a single TLD over the xiphisternum is an alternative measure of breast irradiation in women with the x-ray equipment and projections used in this study; however, it may overestimate the mean glandular dose.

Risks Are Dependent on Fluoroscopy Unit Used

The dose rate at skin entrance from the fluoroscopy unit used in this study was lower than those from some fluoroscopy units commonly used for interventional cardiology. The patient dose rate from the unit used in this study ranged from 5 to 17 mGy/min for field sizes 15 to 23 cm and tube current settings 0.5 to 4 mA with 20-cm tissue equivalent material placed on the tabletop at 90-cm focus to image intensifier distance (FID) and 60-cm focus to detector distance (FDD).

Although an intercomparison of doses from different fluoroscopy units was not an aim of this study, it must be pointed out that there can be a wide range in actual doses from different equipment. For example, the skin entrance–absorbed dose rate from another commonly used fluoroscopy unit we have tested was 24 to 60 mGy/min for 100-cm FID and 80-cm FDD, which equates to 43 to 107 mGy/min at 60-cm FDD. The patient skin doses and corresponding risks could therefore have been 3 to 5 times higher for the same fluoroscopy times if the other fluoroscopy unit had been used. The output dose rate is affected by many factors such as total filtration, programmable added filtration, generator design and the corresponding kVp waveform, available tube current, and pulsing techniques. The relatively low patient doses in our study are most likely to be due to the relatively low tube currents (0.5 to 2 mA) and the high total beam filtration.

Clinical Implications

Prolonged fluoroscopy during radiofrequency ablation is likely to cause a small increase in the lifetime risk of fatal malignancy. This risk is approximately one third of the estimated risk from radiofrequency ablation reported previously. The risk is increased in obese patients and in laboratories with high-output fluoroscopy units.
equipment that can operate for long periods with high tube currents necessitates caution because of the high skin doses possible and reports of skin doses of up to 20 Gy, causing severe burns.23 Such high-output equipment will of course significantly increase the risks of malignancy from the use of fluoroscopy for a minimal increase in image quality.

The risk of a fatal malignancy during I lifetime in the absence of radiation exposure (other than natural background radiation) is 20%.14 Use of fluoroscopy for 1 hour during radiofrequency ablation would make this risk 20.03% for the patient. This small risk associated with the procedure should be looked at in the light of the benefits associated with the procedure. The procedure is curative in >85% of patients. It obviates the need for lifelong antiarrhythmic drug therapy with its associated side effects. It avoids the possible proarrhythmia associated with antiarrhythmic drug therapy, which could be fatal.24 The quality of life is likely to be better for the patients cured of their arrhythmia than those who are dependent on lifelong antiarrhythmic therapy.25 It is more cost-effective in the long term than antiarrhythmic drug therapy.26,27 It also avoids the risks associated with cardiac surgery, which could be as much as 5%,26,27 and is cheaper and more cost-effective than cardiac surgery for supraventricular tachycardia.30

Minimization of Radiation Exposure to Patients

Every effort should be made to decrease the radiation exposure to patients during radiofrequency ablation. The duration of fluoroscopy should be minimized as much as possible. This is likely to occur with increased experience and skill of operators.38 However, prolonged fluoroscopy use is still likely in complex cases with multiple pathways.4 Operators should ensure that high-output fluoroscopy units are not used for procedures such as radiofrequency ablation, in which prolonged fluoroscopy usage might occur.

Use of pulsed fluoroscopy is likely to decrease radiation exposure to the patient.32 Routine use of collimation as was done in this study is also likely to decrease radiation exposure to the patient.39 Large increases in exposure result from using smaller intensifier fields and this should be kept to the minimum.40 Single-phase x-ray generators use a higher exposure rate to achieve a given image quality than do fluoroscopic devices with medium frequency or 3-phase generators.9

The most effective means of checking the cumulative radiation dose to the patient during a study is the installation of a dose-area product meter. The operator can then not only monitor the dose at any stage, but also (if wished) estimate the effective dose and thus risk at the completion of a procedure. The latter becomes even more important when very long or multiple procedures are needed on an individual patient.

Last, the small risks of radiation-induced malignancy should be explained to patients undergoing procedures requiring prolonged fluoroscopy or acquisition times to ensure that they are fully informed of the potential risks.

Acknowledgments

(1)XDOSE is a computer program for Monte Carlo calculation of the ICRP dose index “effective dose” from the dose-area product. XDOSE uses data files from Software report NRPB-SR262. The XDOSE executable file is available from the National Radiation Laboratory, PO Box 25 to 099, Christchurch, New Zealand. The data files, known as Software report NRPB-SR262 must be purchased directly from the National Radiological Protection Board (NRPB), Chilton, Oxon, OX11 0RQ, UK. The authors are indebted to John Cranker, Radiation Safety Technician, for his technical help, Dr Karen Byth for her expert statistical analysis, Dr John Heggie for his helpful comments, and to the nurses and technicians of the electrophysiology laboratory for their assistance.

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