Obesity Is a Major Determinant of Radiation Dose in Patients Undergoing Pulmonary Vein Isolation for Atrial Fibrillation

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Objectives This study sought to evaluate the impact of obesity on patient radiation dose during atrial fibrillation (AF) ablation procedures under fluoroscopic guidance.

Background Obesity is a risk factor for AF and its recurrence after ablation. It increases patient radiation dose during fluoroscopic imaging, but this effect has not been quantified for AF ablation procedures.

Methods Effective radiation dose and lifetime attributable cancer risk were calculated from dose-area product (DAP) measurements in 85 patients undergoing AF ablation guided by biplane low-frequency pulsed fluoroscopy (3 frames/s). Three dose calculation methods were used (Monte Carlo simulation, dose conversion coefficients, and depth-profile dose curves).

Results Median DAP for all patients was 119.6 Gy·cm² (range 13.9 to 446.3 Gy·cm²) for procedures with a median duration of 4 h and 83 ± 26 min of fluoroscopy. Body mass index was a more important determinant of DAP than total fluoroscopy time (r = 0.74 vs. 0.37, p < 0.001), with mean DAP values per hour of fluoroscopy of 58 ± 40 Gy·cm², 110 ± 43 Gy·cm², and 184 ± 79 Gy·cm² in normal, overweight, and obese patients, respectively. The corresponding effective radiation doses for AF ablation procedures were 15.2 ± 7.8 mSv, 26.7 ± 11.6 mSv, and 39.0 ± 15.2 mSv, respectively (Monte Carlo). Use of conversion coefficients resulted in higher effective dose estimates than other methods, particularly in obese patients. Mean attributable lifetime risk of all-cancer mortality was 0.060%, 0.100%, and 0.149%, depending on weight class.

Conclusions Obese patients receive more than twice the effective radiation dose of normal-weight patients during AF ablation procedures. Obesity needs to be considered in the risk-benefit ratio of AF ablation and should prompt further measures to reduce radiation exposure. (J Am Coll Cardiol 2007;50:234–42) © 2007 by the American College of Cardiology Foundation

Catheter ablation of atrial fibrillation (AF) is gradually gaining worldwide acceptance as an effective therapy for patients with symptomatic and drug-refractory AF. In spite of a growing use of nonfluoroscopic mapping systems to guide these complex procedures, many centers still rely on biplane fluoroscopic guidance for catheter navigation and ablation. A worldwide survey on AF ablation conducted between 1995 and 2002 showed that 77% of participating centers used a lasso approach with fluoroscopic guidance to electrically isolate pulmonary veins from the left atrium (1). Even when other systems are used, fluoroscopy forms the cornerstone of the procedure.

Like all ionizing radiation, fluoroscopy is associated with risks. Skin damage at the site of the X-ray beam entrance can occur above a certain radiation dose, with increasing severity at higher doses (i.e., a deterministic effect) (2). Stochastic effects such as radiation-induced cancer and genetic defects occur with a higher probability at higher doses, without a distinct dose threshold. Modern fluoroscopy systems operate under automatic exposure control, with tube voltage (kV) and tube current (mA) adjusted to patient attenuation. They therefore result in a higher radiation load in obese patients. The influence of patient size on effective doses during these procedures is generally not considered and not documented. This may be especially important, however, in candidates for AF ablation because

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recent data showed an increased prevalence of AF in obese patients (3) and a higher recurrence rate after ablation (4). Furthermore, the increase in patient radiation dose caused by obesity is expected to be more pronounced for AF ablation than for other interventional cardiac procedures because the former generally requires longer procedures and fluoroscopy times.

The goal of our study was to calculate effective radiation doses in a large group of patients undergoing pulmonary vein isolation (PVI) and to determine the influence of patient body mass on this dose and its associated stochastic and deterministic risks.

Methods

Patients and procedures. We report on 85 patients (64 men and 21 women) who underwent a first radiofrequency ablation of focally induced paroxysmal or persistent AF. Patients in whom important underlying atrial structural changes were assumed (dilated left atrium, congestive heart failure, older age) were not considered for ablation in our center. Data on patient height, weight, and body mass index (BMI) were collected as part of the clinical routine. The BMI was classified as normal (<25 kg/m²), overweight (25 to <30 kg/m²), and obese (≥30 kg/m²) according to the World Health Organization/National Institutes of Health classification scheme (5).

Ablation was performed under general anesthesia with propofol and mechanical ventilation. All catheters were introduced via femoral veins. Transseptal catheterization was performed using 2 transseptal sheaths (SR 0, St. Jude Medical, Daig Division, Inc., Minnetonka, Minnesota). Intravenous heparin was given to maintain an activated clotting time of 250 to 350 s during the procedure. Mapping of pulmonary vein (PV) potentials was performed with a deflectable decapolar catheter with a distal ring configuration (Lasso, Cordis-Webster, Diamond Bar, California). Ablation was performed using temperature feedback with a target temperature of 50°C and a maximum power output of 30 W. The end point for PV isolation was the creation of bidirectional conduction block from atrium to PV and vice versa. All 4 PVs were isolated in 73 of 85 (86%) patients, whereas only arrhythmogenic PVs were targeted in the remaining 12 patients (6). The PV angiograms were performed before and after PV isolation. Linear ablation lesions from the left inferior PV toward the mitral valve and/or in the roof of the left atrium were applied in 14 patients (16%) if AF was still inducible after PVI. The inferior flutter isthmus between tricuspid ring and inferior caval vein orifice was ablated in 62 of 85 patients (73%) during the same procedure (and was ablated before in 19 others). Flutter ablation was guided by right atrial angiography in 52 of 62 patients (84%) (7).

Biplane fluoroscopy and dose-area product (DAP) measurements. All procedures were performed under fluoroscopic guidance with a Coroskop C biplane image intensifier system (Siemens, Erlangen, Germany). The system was routinely set to pulsed fluoroscopy at 3 frames/s and a cine frame rate of 12.5 frames/s to minimize radiation exposure. The image intensifier diameter of 23 cm was used for all patients with beam collimation to the region of interest. Standard 30° right anterior oblique (RAO)/60° left anterior oblique (LAO) fluoroscopic view angles were adjusted to the intracardiac catheter positions as outlined previously (8). The half-value layer (HVL) of each tube was 5.4, respectively, 5.6 mm of aluminum at 80 kV.

Radiation dose was quantified with DAP meters incorporated in the fluoroscopy unit. These DAP meters use an air ionization chamber mounted just beyond the X-ray collimators and integrate exposure over the entire image field. The DAP meters were calibrated yearly. The DAP was recorded (in Gy·cm²) as a total for both X-ray tubes, together with the procedure time and total fluoroscopy time in minutes. The DAP measurements have been proven to correlate reasonably well with effective radiation dose, and therefore reflect the probability of stochastic effects (9,10).

Conversion of DAP measurements to effective dose. The concept of effective dose is used in radiation protection to compare the stochastic risk of a nonuniform exposure of ionizing radiation with the risks caused by a uniform exposure to the whole body (11). The effective dose is expressed in sievert (Sv) or millisievert (mSv), and is found by calculating a weighted average of the equivalent dose to different body tissues, with the weighting factors designed to reflect the different radiosensitivities of the tissues. This parameter permits comparison of risks among different individuals and among different imaging modalities (e.g., comparison of effective dose between coronary angiogram and computed tomography coronary angiography (12).

In this study, the effective dose was calculated for each patient using 3 methods. The primary method used a PC-based X-ray Monte Carlo program, PCXMC (Radiation and Nuclear Safety Agency, Helsinki, Finland) (13). This software allows Monte Carlo simulation of fluoroscopic radiation exposure to a hermaphrodite phantom [modified Cristy-phantom (14)] based on fluoroscopic view angles, patient weight and height, field size, and focus to skin distance. Because DAP values were only recorded by the fluoroscopy system as a total for both RAO and LAO imaging planes, the relative contribution of each plane to total DAP values was estimated in 5 reference procedures.
and was found to be about equal for both. Therefore, DAP values were divided by 2 to calculate effective dose contribution from each imaging plane. We used $13 \times 13$-cm field dimensions at the entrance of the patient’s skin, a 60-cm focus-skin distance, an HVL of 5.5 mm aluminum, and an 80-kV beam to further characterize the fluoroscopic exposure in all patients, based on the characteristics determined from the reference procedures. Effective dose results from this method were used for calculation of the radiation-induced lifetime attributable risk for cancer.

The second method used to calculate effective dose from DAP measurements was based on dose conversion coefficients (15). This method is simpler because it only requires multiplying the DAP measurements with a coefficient to estimate effective dose. However, conversion coefficients are only available for a limited number of fluoroscopic projections, are not adapted to different patient sizes, and depend on the fluoroscopic protocol used in different centers. Conversion coefficients developed by the National Radiological Protection Board (NRPB) (16) have been most frequently used in previous studies (17,18). We used the NRPB dose conversion coefficients (80 kV, 5.0 mm Al HVL) for the $45^\circ$ RAO and $45^\circ$ LAO projections of the heart and compared these estimates with the results of our software-based simulation.

In the third method, effective dose was calculated with software based on depth dose and profile curves (WinODS, RTI Electronics AB, Mölndal, Sweden). This software uses an Alderson-Rando type phantom model, adjusted to each patient’s height, weight, and gender. The weight of the patient is compared with the mean weight of the population having the same height as the patient. If the patient is heavier than the statistical mean, adipose tissue is being added between the contour and the organs of the phantom. The addition of adipose tissue is a feature not used in PCXMC, which only applies a scaling factor to adjust for the patient’s height and weight. Calculation in WinODS was performed with the same exposure parameters (field dimensions, focus-skin distance, HVL, and tube voltage) as for the PCXMC software.

Estimation of lifetime attributable cancer risk from PVI. Effective dose values from the PCXMC software were used to calculate the radiation-induced lifetime attributable risk for cancer incidence and cancer mortality in each patient, based on the risk estimates recently published in the BEIR VII report on the health risks from exposure to low levels of ionizing radiation (19). The cancer risk estimates in the BEIR VII report are based on the linear-no-threshold risk model, assuming that the risk of cancer proceeds in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increase in risk to humans. To calculate the lifetime attributable risk for cancer incidence and mortality at patient-specific ages, linear interpolation was used for ages not explicitly provided in the BEIR VII report.

### Statistical Analysis

Summary values are given as mean ± SD or median for not-normally-distributed values. The Shapiro-Wilk W test was used to test for normality. Comparisons between continuous variables in the 3 patient groups were made by one-way analysis of variance with Scheffe post-hoc analysis. Differences in proportions between groups were evaluated with the Fisher exact test. A value of $p < 0.05$ was considered significant.

A Pearson correlation coefficient was calculated for simple linear regression analysis, and a Hotelling $t$ test was used to assess differences between related correlations. Multiple linear regression was performed to adjust for patient gender, BMI, fluoroscopy time, and addition of a flutter ablation or linear lesions.

The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the manuscript as written.

### Results

#### Patients and procedures. Patient and procedural characteristics are summarized in Table 1. Mean patient BMI was $26.6 \pm 4.1$ kg/m$^2$, corresponding well with values previously published in larger groups of AF patients (20). Sixteen patients (19%) had a BMI $\geq 30$ kg/m$^2$, the criterion for obesity.

Nineteen patients had already undergone ablation for atrial flutter in the past. Pulmonary vein isolation and cavotricuspid isthmus ablation were acutely successful in all patients in whom they were performed. This required a mean fluoroscopy time of 83 $\pm$ 26 min in procedures with a median duration of 4 h. Procedural and fluoroscopy times tended to be somewhat higher in overweight and obese patients, although these differences were not statistically significant (procedural time 237 $\pm$ 46 min, 258 $\pm$ 76 min, and 266 $\pm$ 54 min in normal, overweight, and obese

#### Table 1. Patient and Procedure Characteristics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, yrs</td>
<td>49 $\pm$ 9 (64 male, 21 female)</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>82 $\pm$ 15</td>
</tr>
<tr>
<td>Height, cm</td>
<td>175 $\pm$ 9</td>
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<tr>
<td>BMI, kg/m$^2$</td>
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<td>BMI 25 to $&lt;30$ kg/m$^2$, n (%)</td>
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<tr>
<td>BMI $\geq30$ kg/m$^2$, n (%)</td>
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</tr>
<tr>
<td>Procedure time, min</td>
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</tr>
<tr>
<td>Fluoroscopy time, min</td>
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</tr>
<tr>
<td>RAO angulation, °</td>
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<tr>
<td>LAO angulation, °</td>
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<tr>
<td>DAP value, Gy cm$^2$</td>
<td>119.6 (13.9–446.3)</td>
</tr>
<tr>
<td>Effective dose, mSv</td>
<td>22.4 (3.3–71.4)</td>
</tr>
</tbody>
</table>

Data are mean ± SD or median (range) for not-normally-distributed variables. *Effective dose as calculated with PCXMC simulation software.

BMI = body mass index; DAP = dose-area product; LAO = left anterior oblique view; RAO = right anterior oblique view.
patients, respectively, $p = 0.25$; fluoroscopy time 76 ± 28 min, 85 ± 25 min, and 89 ± 24 min, respectively, $p = 0.22$). Nine patients (11%) required a repeat PVI procedure for recurrent AF. These repeat procedures were not included in this study.

**DAP and influence of patient size and body mass.** Despite the use of pulsed fluoroscopy at 3 frames/s, PVI procedures resulted in a relatively high patient radiation exposure with a median DAP value of 119.6 Gy·cm² (range 13.9 to 446.3 Gy·cm²). The correlation between fluoroscopy time and DAP was relatively weak ($r = 0.37$, $p < 0.001$) (Fig. 1A). Figure 1B shows that there is a significantly stronger influence of BMI on patient radiation dose ($r = 0.74$, $p < 0.001$). The strong correlation between BMI and DAP remained highly significant when multivariately corrected for patient gender, fluoroscopy time, and addition of a flutter ablation or linear lesions, with partial correlation coefficients of 0.74 for BMI ($p < 0.001$) and 0.22 for fluoroscopy time ($p = 0.04$). The addition of a right atrial flutter ablation was also significantly correlated with total DAP (partial correlation coefficient 0.23, $p = 0.001$). The percentage of patients undergoing left atrial linear ablation was comparable in the groups of normal-weight and obese patients (28.6% vs. 25.0%), and the addition of linear lesions did not significantly correlate with total DAP on multivariate analysis. The mean radiation doses for patients in the 3 BMI groups are represented in Figure 2, expressed both as DAP for the total procedure and per hour of fluoroscopy. During 1 h of fluoroscopy, obese patients received 3.2 times the DAP of patients with a normal BMI, resulting in mean DAP values of 184 ± 79 and 58 ± 40 Gy·cm²/h respectively ($p < 0.001$).

A DAP trigger level of 300 Gy·cm² has been proposed for interventional cardiac procedures to alert the operator for possible skin injury of the patient (9,17). A DAP value >300 Gy·cm² occurred in 6 procedures (7%), and 5 of these procedures involved obese patients ($p < 0.001$). No clinical manifestations of radiodermatitis were evident after the procedure and at 6-week follow-up, and there were no reports of any adverse effects from patients.

**Effective dose.** The median effective dose for all procedures, as calculated with the PCXMC software (method 1), was 22.4 mSv with a range from 3.1 to 71.4 mSv. Again, the effective dose was highly dependent on patient size (Fig. 3). For obese patients, the mean total effective dose for a PVI procedure was 39.0 ± 15.2 mSv, compared with 15.2 ± 7.8 mSv for patients with a normal BMI ($p < 0.001$). When calculated per hour of fluoroscopy, obese patients received a 2.2-fold higher effective dose (27.3 vs. 12.5 mSv/h).

Calculation with the NRPB conversion coefficients (method 2; RAO 0.251 mSv·Gy⁻¹·cm⁻², LAO: 0.223 mSv·Gy⁻¹·cm⁻²) resulted in higher estimates of the received effective dose compared to the PCXMC calculations. The difference between the 2 calculation methods increased with higher BMI values and was significant in the overweight and obese patient groups (Figs. 3 and 4A). Therefore, effective dose estimations of the PCXMC program were used to calculate a local center-specific dose conversion coefficient from total DAP to effective dose during PVI procedures in our center. The calculated conversion coefficient was 0.188 mSv·Gy⁻¹·cm⁻² for the entire patient group, but was also highly dependent on patient size: 0.218 mSv·Gy⁻¹·cm⁻² for patients with normal BMI versus 0.180

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**Figure 1:** *Patient Radiation Dose Versus Fluoroscopy Time and BMI*

Scatter plots showing the relationship between patient radiation dose and total fluoroscopy time (A) and body mass index (BMI) (B). There is a significantly stronger correlation between BMI and radiation dose than between fluoroscopy time and radiation dose. DAP = dose-area product; $P_{\text{DAP}(R1-R2)} = p$ value for difference between correlation coefficients; $R_{1,2} =$ correlation coefficients.
and 0.154 mSv·Gy\(^{-1}\)·cm\(^{-2}\) for overweight and obese patients respectively (p < 0.001 for both).

Calculation with the WinODS software (method 3) resulted in slightly (but not significantly) higher effective dose estimates than with the PCXMC software (Fig. 3). Higher effective dose estimates in female patients were the main reason for this discrepancy (Fig. 4B). This difference was, however, not statistically significant even for the group of female patients only, given the small number of women included in the study (n = 21, p = 0.13). When considering only male patients, the differences in the mean effective dose in the 3 BMI categories were ≤1 mSv for both programs (PCXMC vs. WinODS: 16.5 vs. 15.5 mSv for normal weight, 26.6 vs. 26.5 mSv for overweight, and 44.0 vs. 44.5 mSv for obese patients). The higher estimates for female patients compared with Monte Carlo-based dose determinations have been reported before for WinODS and are mainly caused by anatomical differences between the phantom models (21).

**Radiation-induced lifetime attributable cancer risk.** The lifetime risks for the incidence and mortality of cancer attributable to an effective radiation dose associated with PVI in our center are represented in Table 2. To put these risks into perspective, the baseline lifetime risk for solid cancer mortality in the general population is also included (19).

**Discussion**

Our study is the first to report DAP measurements of the radiation exposure in a large group of patients undergoing PVI for AF to calculate effective dose and related risks. It shows that these procedures are associated with a relatively high patient radiation exposure despite the use of pulsed fluoroscopy at 3 frames/s. Moreover, our findings highlight the important effect of patient mass on effective dose during these procedures: the fact that patient BMI is a more...
important determinant of the effective dose than total fluoroscopy time is generally not recognized. This finding is explained by the automatic exposure control used in current fluoroscopy systems, adapting tube voltage (kV) and tube current (mA) to preserve radiation levels at the image receptor for different levels of patient attenuation. It implies that the indication for ablation should be weighed more carefully in obese patients, and that these patients in particular would benefit from the lower radiation exposure associated with nonfluoroscopic mapping systems.

Patient radiation exposure during AF ablation. Few data have been published regarding patient radiation exposure during AF ablation. Measurement of peak skin doses (PSDs) were performed in 2 previous reports to estimate patient radiation exposure. Macle et al. (22) reported on the radiation dose measured with dosimeters placed over the xyphoid in 43 patients undergoing ablation for paroxysmal AF. They measured a median PSD of 1.110 mSv. However, the use of only one dosimeter, possibly not at the focal point of radiation, probably led to a great underestimation of PSD. This problem was overcome in a study by Lickfett et al. (23), by using a vest containing 50 to 60 dosimeters to measure PSD in 15 patients undergoing AF ablation. They measured a PSD of 1.0 ± 0.5 Gy in the RAO and 1.5 ± 0.4 Gy in the LAO projection, doses approximately 1,000-fold higher than those reported by Macle et al. (22). They estimated an overall mean effective dose of 24.4 mSv in patients undergoing AF ablation.

Estimation of effective doses based on DAP measurements have only been published in 2 patients undergoing AF ablation, included in a study by Efstathopoulos et al. (24). They reported a DAP of 133.4 Gy·cm² and effective doses of 16.6 to 30.1 mSv, according to calculations based on dose conversion coefficients and computer simulation respectively.

Our results illustrate that the use of NRPB conversion coefficients (16), published for patients with standard dimensions (weight 73 kg, height 179 cm, BMI 22.8 kg/m²), result in higher effective dose estimates when they are applied to DAP measurements from obese patients. This finding is explained by the fact that obese patients provide more natural shielding of the sensitive organs to the radiation beam by the presence of a larger amount of fat tissue. From the geometrical point of view, it is possible that for certain tube angulations, the traveling distance of photons from the entrance skin point to affected organs is increased, consequently reducing the organ dose and effective dose. A certain DAP value therefore results in a lower effective dose in obese than in normal-weight patients. This can be derived from our study by: 1) the lower local conversion coefficients calculated (based on Monte Carlo simulation) for obese patients; and 2) the fact that increases in effective dose between different BMI categories were smaller than the corresponding increases in DAP values. Consequently, published conversion coefficients have to be used cautiously, not only considering the used fluoroscopy protocol but also the size of the patient (25). Preferably, every laboratory should determine its own conversion coefficients for the 3 BMI groups.

Obesity and patient radiation exposure: clinical implications. The relationship between patient weight and radiation dose has been established in invasive cardiologic studies other than AF ablation. Kuon et al. (26) found a relation of patient dose rate (DAP/time) and BMI comparable to the one found in our study. The resulting increase in dose per procedure, however, is much higher in our series because of the complex nature of AF ablation and associated long fluoroscopy times. The correlation between BMI and DAP in our study is much stronger than reported for other invasive cardiac studies ($r = 0.74$ vs. $0.37$ as reported by Kuon et al. [26]) because the relative differences in fluoroscopy time are more important during short procedures.
During long procedures, time differences are relatively smaller and variation in dose rates related to BMI have a larger impact on the cumulative dose.

The high radiation exposure (39.0 ± 15.2 mSv) observed in obese patients in our study results in a worse risk-benefit ratio and should be considered when weighing the indication for AF ablation under fluoroscopic guidance. Several considerations underscore the clinical importance of this finding. Obesity is a rapidly growing problem in an increasing number of countries worldwide, with a prevalence of >30% in the U.S. (27). It has been shown to be an independent risk factor for AF with an adjusted 50% risk increase for developing AF (3). Furthermore, recent data suggest that obese patients have higher rates of AF recurrence after radiofrequency ablation and are therefore more likely to undergo repeat procedures (4).

**Limiting radiation exposure in patients referred for AF ablation.** The most important way to reduce radiation exposure during AF ablation is the use of nonfluoroscopic mapping systems when available, allowing a reduction of fluoroscopy time in the range of 25% to 50% (28–30). If fluoroscopic guidance is used, minimizing fluoroscopy time as much as possible and use of pulsed fluoroscopy are mandatory. Auffrichtig et al. (31) showed average dose savings of 22%, 49%, and almost 80% at 15, 7.5, and 3 frames/s, respectively (32). The use of flat-panel detectors instead of image intensifiers in newer fluoroscopy systems possibly allows a dose reduction because of their higher detector sensitivity (i.e., detective quantum efficiency) (33). However, the use of flat-panel detectors does not automatically translate into better image quality and dose efficiency in clinical practice, because many other parameters influence the patient radiation dose in a clinical setting (34,35). New features such as retrospective fluoroscopy storage and different operational dose levels for fluoroscopy nevertheless offer additional opportunities for patient dose reduction.

An additional recent source of patient radiation exposure is the imaging of the left atrium and PVs by multislice cardiac computed tomography, which is increasingly performed before AF ablation. It can add an additional effective dose in the range of 5 to 20 mSv, which is proportionally important compared with the dose of the ablation procedure itself (median 22.4 mSv) (Table 1) (36). Again, patient weight is likely to be a strong determinant of the computed tomography-related dose. When available, gadolinium-enhanced magnetic resonance imaging angiography is therefore preferable given the lack of extra radiation exposure to the patient.

**Radiation-induced carcinogenic and genetic effects.** Data on the health effects of ionizing radiation are largely based on studies on survivors of the Hiroshima and Nagasaki atomic bombs. Although the atomic bomb survivor analyses often have been considered as high-dose studies, in fact, >50% of the exposed individuals in the cohort (26,300 individuals) received doses <50 mSv (37). Based on these epidemiologic data, good evidence exists of an increased cancer risk in humans for an acute exposure at doses above 10 to 50 mSv (37). At lower doses, epidemiologic data alone are insufficient to establish the shape of the dose–response relationship, and risk modeling must be performed. According to the linear–no-threshold risk model adopted in the recent BEIR VII report (19), the risk for solid cancers at low doses (<100 mSv) can be estimated by linear extrapolation. This assumption is, however, not uniformly accepted and is still controversial. For example, a comparable report from the French National Academy of Medicine, although largely based on the same data, doubts the validity of the linear–no-threshold risk model in the evaluation of the carcinogenic risk of low doses (<100 mSv) and even more for very low doses (<10 mSv) (38). This lack of consensus reflects the complexity of the radiation dose–response phenomenon, and further research is needed to reduce uncertainty and further elucidate various mechanisms by which low-level radiation may induce cell damage.

The lifetime attributable risks for cancer incidence and cancer mortality should not be misinterpreted and must
be seen in the larger clinical context of lifetime risk of cancer mortality (Table 2). The risk of genetic effects and heritable diseases has been found to be very low at doses encountered in our patient series. No statistically significant adverse effects have been detected in children of atomic bomb survivors subjected to radiation doses of 400 mSv or less (19).

**Study limitations.** We did not perform direct measurements of PSD with dosimeters placed at the patient’s body surface. The DAP values do not directly reflect PSD, and quantitative evaluation of PSD was therefore not a part of this study. The DAP was measured as a total for fluoroscopy in RAO and LAO projections, including cine sequences, as this was a limitation of the radiographic equipment. To calculate effective doses, the relative contribution of RAO and LAO imaging planes to the total DAP was estimated from a subset of reference procedures and not recorded in each individual procedure. The difference in effective dose values calculated for RAO and LAO projections was, however, only $0.002 \pm 0.008 \text{ mSv/Gy}\cdot\text{cm}^2$. Minor changes in the relative RAO/LAO contribution are therefore expected to have only a very limited impact on the calculated total effective dose for these procedures. A 80-kV tube voltage was used in all patients to calculate effective doses. Higher tube voltages (90 to 100 kV) during procedures in obese patients can lead to higher effective doses for a given DAP value. Our results may therefore even underestimate to some extent the effect of obesity on the effective dose during these procedures.

**Conclusions**

Despite the use of pulsed fluoroscopy at 3 frames/s, ablation of AF under fluoroscopic guidance results in high patient radiation exposure. When performed in obese patients, these procedures are associated with more than twice the patient effective radiation dose. Together with the higher incidence of AF, higher recurrence rate after ablation, and presumably higher doses during associated preprocedural imaging, one needs to consider the higher carcinogenic risk in these patients in the risk-benefit evaluation of ablation.

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