Radiation Exposure During Radiofrequency Catheter Ablation of Accessory Atrioventricular Connections

Hugh Calkins, MD; Loren Niklason, PhD; Joao Sousa, MD; Rafel El-Atassi, MD; Jonathan Langberg, MD; and Fred Morady, MD

Background. Catheter ablation of accessory atrioventricular (AV) connections has been demonstrated to be effective in more than 85% of patients. One of the risks of this procedure is radiation exposure during the fluoroscopic imaging necessary to guide catheter manipulation. The objective of the present study was to measure the radiation received by patients and physicians during radiofrequency catheter ablation and to estimate the resultant somatic and genetic risks.

Methods and Results. Radiation exposure to patients and physicians was measured during attempts at radiofrequency catheter ablation of accessory AV connections in 31 consecutive patients. Radiation exposure was measured using thermoluminescent sensors placed on the patient and on the physician. Somatic and genetic risks were estimated based on the radiation levels recorded using these sensors. The durations of fluoroscopy and of the catheter ablation procedure were recorded for each patient. Catheter ablation was successful in 28 of 31 patients (90%). Mean ± SD duration of fluoroscopy was 44 ± 40 minutes. The largest patient radiation dose was measured over the ninth vertebral body posteriorly (median, 7.26 rem; range, 0.31–135.7 rem). Median radiation dose to the thyroid was 0.46 rem (range, 0.06–7.26 rem), and median radiation dose to the posterior iliac crest was 2.43 rem (range, 0.01–8.3 rem). The greatest radiation dose to the operator was recorded at the left hand (99 mrem). Mean radiation dose to the operator's eyes was 28 mrem.

Conclusions. Radiofrequency catheter ablation of accessory AV connections may result in significant radiation exposure to the patient and to the physician. Each hour of fluoroscopic imaging is associated with a lifetime risk of developing a fatal malignancy of 0.1% and a risk of a genetic defect of 20 per 1 million births. Although these risks must be recognized, they are relatively small compared with the risks associated with alternate approaches to management, including no therapy, antiarrhythmic drug therapy, and surgery. (Circulation 1991;84:2376–2382)

Catheter ablation of accessory atrioventricular (AV) connections with radiofrequency energy has been demonstrated to be effective in more than 85% of patients with Wolff-Parkinson-White syndrome or paroxysmal supraventricular tachycardia (PSVT) using a concealed accessory AV connection.1–5 Although complications at the time of the procedure and during short-term follow-up appear to be infrequent,1–5 the long-term risks of the procedure remain unknown. A potential source of risk to the patient and to the physicians performing the procedure is the radiation exposure from fluoroscopic imaging required to guide catheter manipulation. To determine the proper role of radiofrequency catheter ablation of accessory AV connections in the management of patients with PSVT or Wolff-Parkinson-White syndrome, this risk must be evaluated.

See p 2594

The objective of the present study was to measure the radiation exposure to patients and physicians during radiofrequency catheter ablation of accessory AV connections and to estimate the resultant somatic and genetic risks.

Methods

Patient Characteristics

Enrolled into the present study were 31 consecutive patients with Wolff-Parkinson-White syndrome from the University of Michigan Medical Center, Division of Cardiology, Departments of Internal Medicine (H.C., J.S., R.E.-A., J.L., F.M.) and Radiology (L.N.), Ann Arbor, Mich.

Address for reprints: Hugh Calkins, MD, University of Michigan Medical Center, Division of Cardiology, 1500 E. Medical Center Drive, Ann Arbor, MI 48109-0022.

Received April 5, 1991; revision accepted August 6, 1991.
or PSVT using a concealed accessory AV connection who underwent an attempt at radiofrequency catheter ablation of an accessory AV connection. Mean patient age was 35±15 years (age range, 14–67 years). Seventeen patients were women, and 14 were men. No patient had evidence of structural heart disease. Each patient had a history of symptomatic tachycardia with mean symptom duration of 14±13 years. A mean of 2.1±1.8 antiarrhythmic drugs had been ineffective or discontinued due to side effects.

Electrophysiological Testing and Ablation Protocol

Informed consent was obtained under an investigational protocol approved by the Human Research Committee at the University of Michigan. Each patient underwent a diagnostic electrophysiologic study in conjunction with the attempt at catheter ablation. Three 6F quadripolar catheters (USCI) with 1-cm interelectrode spacing were inserted into a femoral vein and positioned in the high right atrium, His bundle, and right ventricle. In patients with left-sided or concealed accessory AV connections, a 7F quadripolar catheter with a central lumen (USCI) or a 6F orthogonal electrode catheter (Mansfield/Webster) was positioned in the coronary sinus via the right internal jugular vein. The goals of the diagnostic portion of the electrophysiological test were to confirm the presence of an accessory AV connection, to determine the baseline electrophysiological properties of the AV node and accessory AV connection, and to localize the accessory AV connection to a general region of the heart.

After preliminary localization of the accessory AV connection, precise mapping within the targeted region was performed with the ablation catheter, which was a 7F quadripolar electrode catheter with a 4-mm distal electrode and a deflectable curve (Mansfield/Webster). Precise mapping was performed by positioning the ablation catheter against the mitral or tricuspid annulus in the region defined during preliminary mapping. Accessory AV connections that were capable of anterograde conduction were localized primarily during sinus rhythm or atrial pacing. Concealed accessory AV connections were localized during orthodromic tachycardia or ventricular pacing.

Catheter ablation was performed using radiofrequency energy delivered as a continuous unmodulated sine wave at a cycle length of 350 kHz (Radionics RF-3B, Burlington, Mass.) between the distal electrode of the ablation catheter and a large skin electrode (Valleylab, Boulder, Colo.) positioned on the chest. From 25 to 36 W was delivered for 10–20 seconds.

Procedure Duration

In each patient, the amount of time required for inserting and positioning catheters, for the diagnostic component of the electrophysiological test, and for the catheter ablation procedure was recorded. The duration of fluoroscopy was also recorded for each procedure. The times required to remove the catheters and to obtain hemostasis were not recorded. The duration of the ablation procedure was limited to 4 hours.

Fluoroscopic System and Radiation Measurements

A Siemens Angioscop D/Polydoros 80 single-plane fluoroscopic system with a 27-cm image area was used to guide the placement of electrode catheters. Automatic brightness control was used, which resulted in a tube potential of 70–109 kV and 1–4.3 mA. The system was calibrated to allow a maximum output of 9.5 roentgens per minute (R/min) at a distance of 30 cm from the image intensifier. The electrode catheters were positioned in the heart using fluoroscopic imaging in the posteroanterior projection. Precise catheter manipulation within the heart was performed in either the 30° left anterior oblique or the 30° right anterior oblique projection. For ablation of right-sided accessory AV connections, the left anterior oblique projection was primarily used, whereas for ablation of left-sided accessory AV connections, the right anterior oblique projection was used to position the catheter against the annulus and the left anterior oblique projection was used for precise localization.

Each patient had six lithium fluoride thermoluminescent dosimeter (TLD) sensors (Landauer TLD-100 3×3×0.9-mm chips) taped to the body before the electrophysiological study and catheter ablation procedure. The minimum detectable amount of radiation (±SD of background) was 10 mrem. One TLD sensor was placed over the thyroid, a second was placed over the xyphoid process anteriorly, and a third was placed on the patient’s back at the level of the ninth vertebral body. The fourth and fifth TLD sensors were placed at the level of the xyphoid process in the left and right midaxillary lines. The sixth sensor was placed on the patient’s back in the midline at the level of the iliac crests to assess gonadal radiation exposure.

Radiation exposure to the operator was measured using six TLD sensors that were taped to the physician before the procedure. Sensors were placed on the physician’s left hand, at waist level outside the lead apron, and at waist level inside the lead apron. A fourth TLD sensor was placed on the physician’s left maxillary process immediately below the left eye, and the last two TLD sensors were placed inside and outside the physician’s thyroid collar. To obtain accurate radiation dose levels (i.e., substantially above the dosimeter’s minimum detectable dose), cumulative exposure to the operator was measured during five or six consecutive procedures. Six sets of TLD sensors were used to assess physician radiation exposure during the study. Each of the physicians involved was experienced in radiofrequency catheter ablation and had participated in a minimum of 75 ablation procedures before initiation of the study. The physicians stood at the patient’s right side and wore standard lead aprons and thyroid collars during the procedures. A lead shield was suspended from
the ceiling and positioned between the physician and the image intensifier.

Estimation of Patient Radiation Exposure and Risk

The absorbed radiation doses for the female breast and thyroid were estimated from the dosimeters placed on the anterior (radiographic beam exit) surface of the patients. The dosimeter placed near the xyphoid was used for estimating the breast dose, whereas the dosimeter placed anterior to the thyroid was used to estimate the thyroid dose. The radiation dose to the active bone marrow was estimated from Rosenstein's tables and computer program of tissue doses for common projections and was scaled by the field size of the radiation beam. Radiation dose to the lung fields was calculated by using the entrance (ninth vertebra) and exit (xyphoid) dosimeters. From the field size and the dosimeters at the axillary lines, we estimated that approximately one third of the total lung volume was exposed to this dose. In calculating the radiation risk, a value of one third of the risk from exposing the entire lung volume to the calculated dose was used. The absorbed dose estimates are accurate to an approximate factor of ±2. Risk estimates also have a large error since the committee's risk estimations are based on whole body exposure. It was necessary to estimate the relative volume of tissue exposed to scale the risk estimations. The errors in risk estimations are also anticipated to be an approximate factor of ±2.

Statistical Analysis

Radiation exposure to the patient was not normally distributed; therefore, these data are expressed as the median exposure plus the range. All other data are presented as mean±1SD. For low-energy radiographs such as those used in this study, 1 rem=1 rad=0.01 Sievert.

Results

Baseline Findings and Ablation Results

Twenty-nine patients were demonstrated to have a single accessory AV connection, and two patients had two accessory AV connections. Twenty-one connections were located in the free wall of the left ventricle, six were posteroseptal, and six were located in the free wall of the right ventricle. The accessory AV connections were successfully ablated during a single session in 28 of 31 patients (90%). The initial attempt was unsuccessful in three patients, who have been rescheduled for a second attempt at a later date.

Procedure Durations

Mean time required for insertion and placement of catheters was 27±11 minutes, mean duration of the diagnostic component of the electrophysiologic test was 12±5 minutes, and mean time required for catheter ablation was 78±77 minutes (range, 10–240 minutes). Mean fluoroscopic time was 44±40 minutes (range, 5–150 minutes).

Radiation Exposure

The amount of radiation exposure to the patients in this study is shown in Table 1. The site receiving the largest amount of radiation was the ninth vertebral body posteriorly (median, 7.26 rem; range, 0.31–135.7 rem). Median radiation exposure at all other sensor locations was less than 2.5 rem.

Shown in Table 2 is the radiation exposure to the physicians participating in the present study. Radia-

---

Table 1. Patient Radiation Exposure

<table>
<thead>
<tr>
<th>Sensor location</th>
<th>Median exposure (rem)</th>
<th>Exposure range (rem)</th>
<th>Exposure rate (mrem/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior thyroid</td>
<td>0.46</td>
<td>0.06–7.26</td>
<td>36</td>
</tr>
<tr>
<td>Anterior xyphoid</td>
<td>1.28</td>
<td>0.16–11.58</td>
<td>58</td>
</tr>
<tr>
<td>Posterior ninth vertebra</td>
<td>7.26</td>
<td>0.31–135.7</td>
<td>447</td>
</tr>
<tr>
<td>Right axillary line</td>
<td>0.93</td>
<td>0.06–9.99</td>
<td>45</td>
</tr>
<tr>
<td>Left axillary line</td>
<td>0.95</td>
<td>0.005–16.8</td>
<td>50</td>
</tr>
<tr>
<td>Posterior iliac crest</td>
<td>2.43</td>
<td>0.005–8.3</td>
<td>64</td>
</tr>
</tbody>
</table>

Sievert = 0.01 rem.

Table 2. Physician Radiation Exposure

<table>
<thead>
<tr>
<th>Sensor location</th>
<th>Mean exposure per badge* (mrem)</th>
<th>Mean exposure per case (mrem)</th>
<th>Exposure rate (mrem/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left hand</td>
<td>513±263</td>
<td>99.3</td>
<td>2.25</td>
</tr>
<tr>
<td>Waist</td>
<td>275±229</td>
<td>53.2</td>
<td>1.21</td>
</tr>
<tr>
<td>Waist, under lead</td>
<td>&lt;10</td>
<td>&lt;2</td>
<td>...</td>
</tr>
<tr>
<td>Left maxilla</td>
<td>146±95</td>
<td>28.1</td>
<td>0.53</td>
</tr>
<tr>
<td>Thyroid, outside lead</td>
<td>81±57</td>
<td>15.6</td>
<td>0.36</td>
</tr>
<tr>
<td>Thyroid, under lead</td>
<td>&lt;10</td>
<td>&lt;2</td>
<td>...</td>
</tr>
</tbody>
</table>

*Each badge was used in five or six consecutive cases. Values given as mean±SD.
Radiation exposure was highest at the operator's left hand. The amount of radiation detected by the sensors located under the lead apron and under the thyroid shield did not exceed the threshold level of the sensors (10 mrem).

**Discussion**

The results of the present study demonstrate that radiofrequency catheter ablation of accessory AV connections by physicians experienced in performing the procedure requires a significant amount of fluoroscopic imaging and results in a moderate amount of radiation exposure to both the patients undergoing the procedure and the physicians manipulating the electrode catheters.

**Patient Radiation Exposure**

The radiation exposure received by patients undergoing catheter ablation of accessory AV connections has not been previously reported. However, several studies have evaluated the radiation exposure during diagnostic cardiac catheterizations and percutaneous transluminal coronary angioplasty (PTCA) procedures.7-9 During these procedures, between 40% and 75% of the total radiation exposure results from fluoroscopy, and the remainder results from cinemangiography.7,8 Cascade et al7 measured the radiation exposure to the posterior thoracic spine and reported a mean skin entrance exposure of 69±61 R during PTCA procedures (mean fluoroscopy time, 47±33 minutes) and 20±16 R of radiation exposure during diagnostic cardiac catheterizations (mean fluoroscopy time, 9±6 minutes; 1 R is approximately equal to 1 rem). Reuter8 measured radiation exposure to patients during diagnostic catheterizations (mean fluoroscopy time, 30±14 minutes) and reported a mean skin entrance exposure of 28 R, an exit exposure over the base of the anterior sternum of 1.1±0.5 R, a thyroid exposure of 0.24±0.12 R, and a mean radiation exposure at the anterior pubic symphysis of 0.012±0.012 R. Faulkner et al9 reported a mean radiation dose during PTCA procedures of 5.5 rad to the ninth vertebral body, 1.1 rad to the xiphoid, 7.6 rad to the right midaxillary line, 0.2 rad to the thyroid, and 0.12 rad to the iliac crest.

The radiation exposure to patients in this study undergoing catheter ablation of accessory AV connections resulted only from fluoroscopy and was in general in a range similar to what has been reported during diagnostic catheterizations and PTCA procedures. The median radiation skin entrance dose to the posterior thoracic spine in the present study was 7.26 rem (range, 0.31-135.7 rem), which is slightly more than the dose reported by Faulkner et al9 during PTCA procedures but less than the radiation dose reported by Reuter8 during cardiac catheterizations or by Cascade et al7 during cardiac catheterizations and PTCA procedures. Median radiation exposure measured at the thyroid was similar to that reported during diagnostic cardiac catheterizations or PTCA procedures.7,8

**Physician Radiation Exposure**

The radiation exposure to the operator during radiofrequency catheter ablation procedures also has not been reported. Several investigators have measured physician radiation exposure during other invasive procedures performed with fluoroscopic imaging, including diagnostic cardiac catheterization and PTCA procedures.8,10 Reuter8 reported mean physician radiation exposure during diagnostic cardiac catheterization at the eye level of 20±16 mR, mean thyroid exposure of 10±4 mR, and mean exposure to the left hand of 13±11 mR. Mean fluoroscopy time during these procedures was 30±14 minutes. Dash and Leaman10 reported a similar degree of radiation dose to the eye of 17 mrad during PTCA procedures and 9 mrad during diagnostic catheterizations. Mean fluoroscopy time reported by Dash and Leaman was 35±18 minutes for PTCA procedures and 13±5 minutes for diagnostic catheterizations.

The levels of radiation exposure recorded during catheter ablation of accessory AV connections in the present study were slightly greater than those reported during diagnostic catheterizations and PTCA procedures. Mean radiation exposure to the left maxilla, in close proximity to the left eye, was 28 mrem; mean exposure to the thyroid was 20 mrem; and mean exposure to the left hand was 99 mrem. The radiation exposure received by the operator's left hand was much greater than that reported during PTCA procedures,8 reflecting the constant placement of the operator's left hand on the ablation catheter as it enters the body from the left femoral area.

**Patient Radiation Risks**

It is difficult to quantify the risk of a fatal malignancy or genetic defect in future generations resulting from radiation exposure received during radiofrequency catheter ablation of accessory AV connections. However, estimates can be made based on studies of atomic bomb survivors and patients radiated for treatment of spondylitis.11-13 The Biological Effects of Ionizing Radiation (BEIR V) Committee's report was used to estimate the radiation risks shown in Table 3.13 The BEIR V Committee's risk estimation models are based on the age of the patient at the time of exposure to radiation. We have used the mean age of our patient population (35 years) to compute radiation risk and estimated the absorbed radiation dose based on the radiation exposure recorded by the TLD sensors that were used in the present study.6,13,14 The values shown in Table 3 are the numbers of predicted excess fatal malignancies contracted over a lifetime per 1 million patients as a result of the radiation dose received during the radiofrequency catheter ablation procedure. Data are presented for the mean fluoroscopy time of 44 minutes and are normalized to estimate the risk per 60 minutes of fluoroscopy time. Table 3 includes risk estimates for patients with leukemia, breast cancer, and lung cancer. Radiation exposure received during radiofrequency catheter ablation of accessory AV con-
connections might also result in other types of fatal cancers such as bone or digestive cancers; however, the incidence would be much lower than those included in Table 3. Thyroid cancer is not usually fatal (mortality/incidence, approximately 0.1), and for this reason thyroid cancer was not included in Table 3.

The estimated risk of a fatal malignancy for the patient radiation exposure measured in the present study is approximately 0.7 per 1,000 patients or one per 1,000 patients per 1 hour of fluoroscopy. This compares with an expected incidence of fatal malignancies of 200 per 1,000 patients in the absence of radiation exposure. Although no previous study has estimated the risk of radiation during radiofrequency catheter ablation, these estimates are higher than those of studies that have estimated the radiation risks during cardiac catheterization and PTCA procedures. Faulkner et al estimated a risk of fatal malignancy of 0.13 per 1,000 patients during cardiac catheterization and 0.08 per 1,000 patients during PTCA procedures. The risk of fatal malignancy was lower for these procedures because of lower measured radiation doses and because Faulkner et al used the International Committee on Radiological Protection (ICRP) risk estimates. The BEIR V Committee’s risk estimates are approximately two-fold to fivefold the previous ICRP estimates.

The BEIR V Committee’s models for genetic radiation risks were used to estimate genetic risks. The committee emphasized genetic effects that manifest themselves in the first generation and did not attempt to estimate the radiation-induced genetic effects for disorders of complex etiology, such as heart disease and cancer. The risk estimation for autosomal dominant abnormalities in the first generation is five to 35 cases per 1 million liveborn per rem, whereas the risk for all genetic disorders would be less than 50 cases per 1 million liveborn per rem.

The absorbed dose to the female gonads was estimated from the dosimeter located near the patient’s iliac crest. We did not attempt to measure the dose to the male gonads; however, the data of Faulkner et al indicated that the male gonads receive approximately one fourth the dose received by the female gonads during cardiac catheterizations and PTCA. Using an exposure level of 0.1 rem to the male gonads and 0.4 rem to the female gonads, the number of predicted genetic disorders would be five and 20 per 1 million births for male and female patients, respectively. In comparison, Faulkner et al estimated the genetic risks of cardiac catheterization or PTCA to be one per 1 million births for men and two to five per 1 million births for women. Although the genetic risks are higher than for cardiac catheterization and PTCA, the genetic risks are nevertheless quite small and substantially less than the somatic risks.

**Physician Radiation Risks**

The amount of radiation exposure received by the catheter operator during the study was small and well below the occupational radiation exposure guidelines established by the National Council on Radiation Protection and Measurements (NCRP). The current guidelines limit the annual whole body (head and trunk) dose to 5 rem; the dose to the lens of the eye to 15 rem; and the dose to other organs, including the skin, extremities, breast, thyroid, and gonads, to 50 rem. Assuming that the radiation exposure measured at the left maxilla approximates head exposure and assuming an average fluoroscopy time of 44 minutes per case, a single operator should be limited to 15 ablation procedures per month. Based on the radiation exposure to the left hand, current NCRP guidelines would limit the number of ablation procedures performed by a single operator to 42 ablation procedures per month. If the average fluoroscopy time is significantly more than 44 ± 40 minutes, these limits must be reduced accordingly.

**Clinical Implications**

Although the risks resulting from radiation exposure during radiofrequency catheter ablation of accessory AV connections must be recognized, they appear to be acceptable compared with the risk associated with alternative treatment strategies. Antiarrhythmic drug therapy is associated with a 3–34% risk of proarrhythmia, which at times may be fatal. Additional organ toxicity is seen with all antiarrhythmic agents and has an incidence of as high as 26% in the case of amiodarone. Because many patients with Wolff-Parkinson-White syndrome or PSVT are women of childbearing age, the risk of congenital defects resulting from pregnancy occurring in the presence of an antiarrhythmic agent must
also be considered. Surgical therapy also carries a risk. Although many series of patients having undergone surgical resection of accessory AV connections report no perioperative deaths,21–23 other series report a perioperative mortality rate as high as 5%.24–26 The mortality risk of general anesthesia alone is approximately 0.1%.27 Thus, in patients with Wolff-Parkinson-White syndrome who undergo radiofrequency catheter ablation of an accessory AV connection, the very small genetic risk and 0.07% lifetime risk of developing a fatal malignancy due to radiation exposure appear to be small relative to the risks associated with other therapeutic approaches.

The risk-to-benefit ratio must also be assessed for asymptomatic patients demonstrated to have Wolff-Parkinson-White pattern on an ECG.28 Klein et al.28 recently estimated the risk of sudden cardiac death in asymptomatic patients with Wolff-Parkinson-White syndrome to be 0.1% per patient-year. In patients with an accessory AV connection capable of rapid conduction during atrial fibrillation, the risk of sudden cardiac death increases to 0.56% per patient-year.28 Thus, in asymptomatic patients with Wolff-Parkinson-White pattern on an ECG who are demonstrated to have an accessory AV connection capable of rapid conduction, the radiation risk associated with catheter ablation of accessory AV connections appears small relative to the risk of sudden cardiac death.

Although the risks associated with radiation exposure during catheter ablation of accessory AV connections appear to be acceptable relative to the risks of alternative therapeutic modalities, these risks are significant, and efforts should therefore be taken to limit radiation exposure. This can be accomplished in several ways. First, fluoroscopy time should be minimized. Physicians performing radiofrequency catheter ablation should be aware of the relation among success rate, procedure duration, fluoroscopy time, and radiation risk. We have found that radiofrequency catheter ablation can be accomplished successfully in 90% of patients with an average of less than 1 hour of fluoroscopic imaging. Although our success rate may have increased by prolonging the duration of our procedures, the risk of radiation-induced fatal malignancies would have also increased at a rate of 0.1% per hour of fluoroscopy. At some point, surgical treatment, which has close to a 100% success rate and a very low risk of mortality, may become safer than continuing the attempt at catheter ablation.

Second, coronary angiography should not be performed routinely in these patients at the time of catheter ablation. This is of little benefit to the patient and results in a significant amount of additional radiation exposure over that resulting from the fluoroscopic imaging necessary to guide catheter manipulation during the ablation procedure.7–9 Third, if available, pulse fluoroscopy should be used because it can reduce radiation exposure by as much as 30%. And last, the radiographic beam should be collimated to the smallest field size necessary for the procedure. These measures will also reduce radiation exposure to the physician performing the study. Further reductions to the radiation exposure received by the physician can be accomplished by wearing lead glasses and by using a team approach in which several physicians share in catheter manipulation.

Acknowledgments

The authors are indebted to the staff of the Clinical Electrophysiology Laboratory for their technical support and to Vanessa J. Sims for her secretarial assistance.

References


KEY WORDS • radiofrequency • Wolff-Parkinson-White syndrome • catheters • ablation • radiation
Radiation exposure during radiofrequency catheter ablation of accessory atrioventricular connections.
H Calkins, L Niklason, J Sousa, R el-Atassi, J Langberg and F Morady

Circulation. 1991;84:2376-2382
doi: 10.1161/01.CIR.84.6.2376

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1991 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on
the World Wide Web at:
http://circ.ahajournals.org/content/84/6/2376

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally
published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the
Editorial Office. Once the online version of the published article for which permission is being requested is
located, click Request Permissions in the middle column of the Web page under Services. Further
information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/