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Radial Artery Access as a Predictor of Increased Radiation Exposure During a Diagnostic Cardiac Catheterization Procedure

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Objectives We sought to determine whether radial artery access is associated with increased radiation exposure during cardiac catheterization and whether this relationship differs between operators, after adjustment for clinical and patient characteristics associated with greater radiation exposure.

Background Although previous studies have demonstrated a relationship between radial access and increased radiation exposure to the patient during fluoroscopy-guided cardiac procedures, such studies did not account for differences in operator technique or clustering of patients, procedure complexity, or patient size. Those studies included data from few operators.

Methods Data were collected prospectively on 5,954 diagnostic cardiac catheterizations performed at a tertiary cardiac center. A multilevel regression analysis was used to determine the relationship between radial artery access and radiation exposure.

Results After adjustment for multiple factors, radial access was associated with increased exposure (beta = 0.22, $p < 0.0001$) when compared with the use of femoral access, as measured using the logarithmically transformed air kerma (LogAK). On average, radial access accounted for a 23% increase in measured AK. This was consistent between operators. There were observed differences in the mean LogAK between operators ($p = 0.0158$), as well as substantial variation in measured LogAK between patients within each operator's practice ($p < 0.001$).

Conclusions Radial artery access cardiac catheterization was associated with increased radiation exposure to the patient when compared with femoral access. The measured AK was still far below the threshold for deterministic effects in most patients studied. Observed variations in AK between and within operators may point to better opportunities to reduce exposure. (J Am Coll Cardiol Intv 2011;4:347–52) © 2011 by the American College of Cardiology Foundation

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Radiation exposure is an unintended consequence of some diagnostic and interventional cardiology procedures (1). Previous observational studies have demonstrated that the use of radial artery access increases the amount of radiation administered during cardiac catheterization/percutaneous coronary intervention (PCI) when compared with the use of the femoral access technique (2–6). However, these studies may not represent a true assessment of this association, as they did not account for potential differences in technique between operators or the clustering effects of patients nested within each operator's practice. Furthermore, the investigators did not control for some characteristics associated with increased radiation exposure, including procedure complexity and patient size, and/or only included data from a small sample of patients and operators. The lone randomized controlled trial specifically comparing radiation exposure to the operator during a diagnostic catheterization/PCI procedure by radial or femoral access included only 1 operator (7). A pilot randomized controlled trial consisting of 50 patients with acute myocardial infarction reported no difference in radiation exposure between procedures using radial and femoral access, although this was a secondary outcome and may have been underpowered for this analysis (8). It is thought that the difference in the magnitude of exposure between radial and femoral access cases may be due to a lack of experience with the radial technique (3). However, previous studies were not designed to evaluate the influence of operator experience.

Abbreviations and Acronyms

AK = air kerma

BMI = body mass index

CABG = coronary artery bypass graft

DAP = dose area product

FT = fluoroscopy time

LogAK = logarithmically transformed air kerma

PCI = percutaneous coronary intervention

PVD = peripheral vascular disease

The purpose of this study is to further investigate if the use of the radial access technique when performing a diagnostic cardiac catheterization is associated with an increased dose of radiation to the patient when compared with the use of the femoral access technique. This study tests the following hypotheses:

1. After the adjustment for several clinical and technical factors thought to be associated with an increase in the radiation dose, the use of radial access during a diagnostic cardiac catheterization will be associated with a higher dose of radiation to the patient when compared with the use of femoral access.
2. The relationship between radial access and increased radiation dose to the patient during a diagnostic cardiac catheterization will significantly differ between operators.

Methods

Population. This study used data that was prospectively collected between July 2006 and December 2008 as part of a local cardiac catheterization registry at a high volume tertiary cardiac care center in Southern Ontario, Canada. Over 7,000 diagnostic cardiac catheterizations and 2,400 PCIs are performed at this center each year. Details regarding the structure of this registry and data quality are described elsewhere (9). There were 16 cardiologists (13 interventional, 3 diagnostic-only) working within the unit during the observation period. All cardiologists performed at least 250 diagnostic cases per year and have experience in both the radial and femoral approach. Patients were only included if they underwent a diagnostic cardiac catheterization with a primary purpose of investigation for coronary artery disease. Patients were excluded if they were: 1) referred for an emergency PCI (e.g., primary or rescue PCI for ST-segment elevation myocardial infarction), simultaneous right heart catheterization, or underwent a booked/ad hoc PCI, or procedures for noncoronary interventions); 2) underwent additional diagnostics with an intravascular ultrasound and/or pressure wire during the diagnostic catheterization procedure; 3) had a procedure that required both radial and femoral artery access, or brachial artery access; and/or 4) the patient had renal dysfunction (defined as having a creatinine >180 μmol/l) and/or were on dialysis at the time of referral to the catheterization laboratory.

Catheterization laboratory equipment and radiation protection protocols. All procedures were performed using a Philips Allura Xper FD10 fluoroscopy device (Philips Medical Systems, Surrey, United Kingdom), each equipped with an MRC-G5 0508 Maximus Rotalix ceramic X-ray tube (Philips Medical, Hamburg, Germany). Each laboratory is equally equipped with a variety of radiation protection equipment, including an adjustable ceiling-mounted transparent shield that is "cut out" to conform to the contours of the patient and table, and a lead skirt along the base of the table to shield scatter from beneath the table. Each operator receives training regarding the use of this equipment as part of his or her radiation safety orientation (as per hospital policy). In addition, a medical radiation technologist is designated to each laboratory during operation. This technologist assists with procedures and is responsible for ensuring that protection to the patient and staff is optimized.

Dependent measure. Radiation exposure for each individual in this study was the cumulative air kerma (AK) measured at the interventional reference point. This is a continuous variable measured in milligray (mGy). Air kerma is the measure of radiation energy absorbed in a unit mass of air (10). Built-in hardware and software provided with each fluoroscopy device was used to measure AK at the interventional reference point. The software defines the interventional reference point as 15 cm from the isocenter of the beam on the X-ray tube side. The measurement of AK is automated and an imaging technology specialist routinely calibrates the device to ensure reliability. The measured AK was logarithmically transformed (LogAK) because the distribution was positively skewed. Therefore, all analyses performed in this study were based on LogAK values.

Previous studies have used fluoroscopy time (FT) and dose area product (DAP) as the dependent measures. We believe AK has an advantage over DAP in this context as it is not affected by coning, and thus, might reflect the true differences in exposure owing to the use of the access site rather than differences owing to the use of coning (if physicians were to systematically use coning during femoral cases rather than radial cases). Also, AK has an advantage over FT in that the relationship between FT and radiation exposure depends on the amount of use of cine film acquisition (which requires a higher output from the X-ray device), whereas AK accounts for X-ray device output intensity. It is possible that radial access may require more FT, but not require more acquired frames, resulting in a higher FT without a significant increase in radiation exposure. The use of FT as the dependent measure could potentially bias the estimation of the relationship between radial access and radiation exposure if physicians were to systematically alter their data acquisition routine (i.e., the ratio of cine to fluoroscopy differs when performing a radial access procedure, compared with femoral access) when this technique was used.

Analyses. This study employed a multilevel regression model. This model has 2 advantages over traditional linear regression in that: 1) one can account for clustering effects of patients within physicians; and 2) the estimate of the association between radial access and AK can be determined for each physician individually. The intercept and the coefficient for radial access were considered random factors. This model adjusted for several potential confounders/predictors. The following factors were considered: body mass index (BMI), previous coronary artery bypass graft surgery (CABG; yes or no), peripheral vascular disease (PVD; yes or no), patient age (years), patient sex (male or female), and if a fellow was assisting with the case (yes or no). Age and BMI were coded as continuous variables, whereas previous CABG, PVD, presence of a fellow, and sex are dichotomous. These were included as fixed factors in the model. All statistical analyses were performed using Statistical Analysis Systems (version 9.1, SAS Institute, Cary, North Carolina).

The fixed factors were chosen based on their potential to increase the magnitude of AK during the procedure. For example, individuals who had a previous CABG will likely require a longer procedure/more acquired frames, as the operator will need to image the grafts in addition to the native coronary arteries, and thus, increasing the likelihood of a higher AK. It is necessary to adjust for BMI, as large individuals may be exposed to a higher dose of radiation, as a higher energy output from the X-ray tube is required to penetrate a greater amount of body tissue to produce images of the quality required for accurate diagnosis (11,12). Furthermore, a great deal of mass around the femoral artery access point can make femoral access difficult. This may prompt the operator to switch to a radial approach on large individuals, thus biasing the measure of radiation exposure against radial access. The presence of PVD can impede the guidance of equipment into the ascending aorta. This may require a greater amount of FT, especially if femoral access is used, as it requires the operator to guide through a longer path of arteries. The presence of a trainee during the case may also be related to the measured AK. It is not uncommon for the operator to acquire additional images when training a fellow or resident. In addition, the case may require more FT if the operator allows the (often less technically proficient) resident or fellow to perform part of the procedure (13).

Results

Data on 5,954 cases were available for analyses. Table 1 shows a comparison between radial and femoral cases regarding the mean LogAK, mean FT, and the factors included in the regression model. Both the unadjusted FT and LogAK is significantly higher for radial access ($p < 0.001$ for both FT and LogAK).

Radial access maintained significance as a positive predictor of LogAK after adjustment for above-mentioned factors ($p < 0.0001$). Table 2 presents the beta coefficient for both radial access and each of the other factors included as fixed effects, as estimated by the multilevel regression model. Model fit was performed using Akaike information criterion. The full model presented here demonstrated improved fit over previous iterations of the model. A chi-square test demonstrated that the presented model has a better fit to the data than the empty model ($p < 0.0001$).

Table 1. Comparison Between Femoral and Radial Cases Based on Factors Included in the Model

	Femoral (n = 4,190)		Radial (n = 1,764)		Total (n = 5,954)	
	n	%	n	%	n	%
Previous CABG	538	12.8	59	3.3	597	10
PVD	263	6.3	181	10.3	444	7.5
Male	2,595	61.9	1,152	65.3	3,747	62.9
Fellow	1,052	25.1	482	27.3	1534	25.8
	Mean	SD	Mean	SD	Mean	SD
Age, yrs	65.4	11.9	63.8	11.4	65.0	11.7
BMI, kg/m^2	28.6	6.9	31.5	10.2	29.4	8.2
LogAK, mGy	6.28	0.58	6.49	0.57	6.34	0.59
Fluoroscopy time, min	3.82	5.57	5.46	8.33	4.30	6.55

BMI = body mass index; CABG = coronary artery bypass graft; LogAK = logarithmically transformed air kerma; PVD = peripheral vascular disease.

JACC: CARDIOVASCULAR INTERVENTIONS, VOL. 4, NO. 3, 2011
MARCH 2011:347–52

Table 2. Beta Coefficients Derived From the Multilevel Model

	Beta Coefficient	p Value
Intercept	4.9520	<0.0001
Age, yrs	0.0024	<0.0001
Female	0.4135	<0.0001
BMI, kg/m^2	0.0211	<0.0001
PVD	0.0285	0.2355
Previous CABG	0.2874	<0.0001
Fellow	0.1050	<0.0001
Radial access	0.2216	<0.0001

Abbreviations as in Table 1.

An examination of the random effects (Table 3) showed that there is variation in the intercepts ($p = 0.0158$). This suggests that physicians differ in their mean LogAK after adjusting for the included factors. However, we cannot reject the null hypothesis that the relationship between radial access and increased radiation dose to the patient during a diagnostic cardiac catheterization will not significantly differ between operators (i.e., "radial slope" in Table 3, $p = 0.0764$). That is, the relationship between radial artery access and increased LogAK is likely similar between physicians. Furthermore, there is no evidence that the effect of radial access (i.e., the slope) depends on the mean LogAK for each physician, after adjustment ($p = 0.0639$). Therefore, our hypothesis that the relationship between radial access and increased radiation dose to the patient differs between operators after adjustment for various factors cannot be supported. It is important to note that whereas variations between physicians are significant, variation in LogAK is primarily between patients within a physician's practice (i.e., intraphysician variance is greater than interphysician variance).

These results are illustrated diagrammatically in Figure 1. Each line in this schematic represents an individual physician. The slope of each line represents the magnitude of the difference in radiation exposure between femoral and radial artery access cases. First, we see that the lines have different intercepts. This means that the average radiation dose differs between physicians. Next, we see that the slope of each line is greater than 0, illustrating that the average radiation dose for radial cases is higher than that for femoral cases. This supports our first hypothesis that radial artery access is associated with increased radiation exposure (compared with femoral access). Finally, we see that the lines are roughly parallel (i.e., the slope of each line does not significantly differ from the others). This means that the magnitude of the difference between radial and femoral cases with respect to radiation exposure is approximately the same among the physicians in this study. Support of our second hypothesis (i.e., that this relationship should differ among physicians) would require these lines to have significantly different slopes.

Table 3. Covariance Parameter Estimates

	Subject	Variance Estimate	Standard Error	p Value
Intercept	Operator	0.0271	0.0126	0.0158
Intercept—radial slope	Operator	0.0147	0.0080	0.0639
Radial slope	Operator	0.0094	0.0066	0.0764
Residual		0.2322	0.0043	<0.001

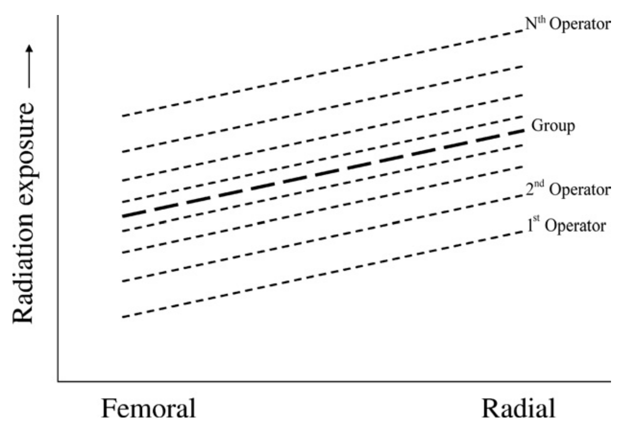

Figure 1. Average Radiation Exposure for Radial and Femoral Access by Physician

Schematic representation comparing radiation exposure between femoral and radial artery access diagnostic cardiac catheterization cases, after adjustment for several patient and procedural characteristics (age, sex, body mass index, peripheral vascular disease, previous coronary artery bypass graft surgery, fellow performing the procedure). Each **line** represents cases from an individual physician. The **bold line** represents the group estimate.

Discussion

Radiation exposure during cardiac catheterization is a concern for both the patient undergoing the procedure and the laboratory staff performing the procedure, and thus health care providers do their best to ensure minimal exposure during the procedure. This study demonstrates that, after adjustment for various factors, the use of radial access during cardiac catheterization is associated with an increase in radiation exposure to the patient when compared with the use of femoral access. This finding is consistent with the previous literature. To our knowledge, this study used the largest patient and physician sample size to date on this topic and is the first to both model the relationship using a multilevel model and use AK instead of FT and/or DAP as the dependent variable.

Based on these findings, some wishing to reduce radiation exposure to the patient and operator during the procedure might consider abandoning routine use of radial access (in favor of femoral access) unless absolutely necessary. However, such a conclusion should be met with caution. Despite the increase associated with radial access, the measured AK was still far below the 2-Gy threshold for deterministic effects in the vast majority of patients in this study (14). Furthermore, the difference in AK between radial and femoral access would constitute a marginal increase in risk of stochastic effects, especially considering the age of most cardiology patients. The physician will need to consider these risks in light of all other potential unintended outcomes, such as differences between radial and femoral access in the risk of bleeding and other potential access site complications (15). However, although the radiation-induced risks associated with an individual procedure may be low, the incremental increase associated with each procedure may result in substantial difference in total lifetime exposure to the operator. For example, assuming a typical patient (male, 65 years of age, BMI of 28.5 kg/m^2, no previous CABG or PVD), the estimated AK based on this model (after conversion from the log scale) would be approximately 23% higher when radial access is employed. Assuming a 20-year career, this would result in exposure equal to approximately 4 additional years if the operator almost exclusively employs the radial rather than the femoral access technique. The increased exposure to the operator may be even higher owing to the close proximity to the X-ray tube when performing a cardiac catheterization via radial access (7). However, this study was not designed to investigate operator dose. Ultimately, the exposure to the operator is contingent on both the magnitude of X-ray tube output during the case and the use of radiation protection devices by the operator.

Some attribute the increase in radiation exposure associated with the use of radial access during cardiac catheterization/PCI to lack of experience by the physician with this technique (6). If this were true, the results observed in this study would suggest that each of the physicians observed is equally inexperienced with the radial technique. This seems improbable given the volume of cases per physician and the differing levels of training/experience within the group (e.g., some physicians are not trained in interventional procedures, when and where the physicians trained varies). Therefore, we do not believe increased experience will diminish the difference between techniques to an insignificant level. Nevertheless, there were significant differences between physicians in the mean LogAK, and even more substantial differences among patients within physicians' practices. Although this may signify inconsistencies in technique, the cause of such variation requires further exploration. Understanding this variation may point to opportunities to reduce radiation exposure during the procedure. Given that this variation appears to overwhelm the additional exposure associated with the radial technique in magnitude, it seems prudent that strategies to reduce radiation exposure should focus on physician technique in general rather than specifically encouraging the use of one access site over another. Furthermore, operators should ensure that best practices regarding the implementation of safety equipment and radiation protection strategies are employed (12,16). However, given the higher AK associated with radial procedures, operators are encouraged to pay careful attention to the use of shielding and coning, and to ensure the patient's arm is extended so the operator can stand at a maximal distance from the X-ray tube during these procedures.

Study limitations. This study has several limitations that are typical of a retrospective observational design. Most notable is the influence of unknown/unmeasured factors on the estimate of beta coefficient for radial access. In addition, this study included data from only 16 operators at a single center. Hox (17) has suggested that models of the type used in this study include a minimum of 20 operators. It is uncertain how the results presented here will translate to other procedures, such as PCI, and/or other operators/centers. The results presented here are consistent with a previous study performed at the same center demonstrating radial access as a potential predictor of radiation exposure during ad hoc PCI procedures (2). However, that particular study was exploratory in nature and did not specifically examine the radial access-radiation exposure relationship. Furthermore, physicians may differ in their proficiency in guiding equipment when using the radial technique. This may result in differences between operators in the relationship between radial access and radiation exposure. Therefore, further research is required to generalize these findings to PCI procedures. This may require a randomized controlled trial, as the variable complexity of PCI procedures may prove difficult to model in the way presented here.

This study also has limitations regarding the dependent variable. First, we did not collect DAP data. This is not seen as a major limitation, as using DAP as the dependent variable could result in misleading estimates of radiation exposure if there is variable use of coning by the operator contingent on choice of access site. However, our lack of DAP data does make it difficult to compare these results with those from previous studies examining radiation exposure when using radial access. Although AK is a better measure of radiation exposure in this context, it is not without error. Air kerma is measured at a fixed point. Therefore, variations in the distance between the patient and the X-ray tube can cause error in the measure of exposure to the patient. For example, if the patient is large, the distance between the X-ray tube and the entry point on the surface of the patient would be reduced, and thus, the magnitude of exposure would be underestimated. In addition, AK (like DAP) does not account for scatter radiation and, thus, may underestimate the magnitude of radiation exposure to both the operator and patient. Data regarding operator exposure (e.g., operator thermoluminescent dosimeter badge readings) were not available. Thus, it was not possible to directly measure increased exposure to the operator due to the use of radial access. Finally, to improve the stability of the model, the dependent measure was log transformed. Results using LogAK may not linearly translate back to those based on AK. Despite these limitations, the study presented here may provide the best evidence to date regarding the relationship between radial access and increased radiation exposure to the patient during a diagnostic cardiac catheterization. Although future studies may potentially better approximate these relationships, based on the results presented, it seems that focusing efforts to explain the reasons for the observed between- and within-physician variations in exposure may result in more fruitful ways to reduce the radiation exposure to both patients and physicians.

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