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CLINICAL RESEARCH

Radial versus femoral access for coronary angiography and intervention is associated with lower patient radiation exposure in high-radial-volume centres: Insights from the RAY'ACT-1 study

Les coronarographies et angioplasties coronaires par voie radiale sont associées à une irradiation du patient inférieure à la voie fémorale dans les centres à haut volume de voie radiale. Données de l'étude RAY'ACT-1

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Abbreviations: BMI, body mass index; CA, diagnostic coronary angiography; KAP, Kerma-area product; PCI, percutaneous coronary intervention; RAY'ACT, Patient's Exposure to X-Ray During Coronary Angiography and Percutaneous Transluminal Coronary Intervention; RIVAL, radial versus femoral.

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KEYWORDS
Coronary angiography;
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Kerma-area product;
Radiation protection

Summary
Background. — Literature suggests that radial access is associated with higher radiation doses than femoral access.
Aims. — To compare patient radiation exposure during coronary angiography (CA) and percutaneous coronary intervention (PCI) with radial versus femoral access.
Methods. — RAY'ACT is a nationwide, multicentre, French survey evaluating patient radiation in interventional cardiology. Variables of patient exposure from 21,675 CAs and 17,109 PCIs performed at 44 centres during 2010 were analysed retrospectively.
Results. — Radial access was used in 71% of CAs and 69% of PCIs. Although median fluoroscopy times were longer for radial versus femoral access (CA, 3.8 vs 3.5 minutes [$P < 0.001$]; PCI, 10.4 vs 10.1 minutes [$P = 0.001$]), the Kerma-area product (KAP) was lower with radial access (CA, 26.8 vs 28.1 Gy·cm^2; PCI, 55.6 vs 59.4 Gy·cm^2; both $P = 0.001$). Differences in KAP remained significant in the multivariable analysis ($P < 0.01$), and in a propensity score-matched analysis ($P = 0.01$). A significant interaction was found between KAP and the percentage of procedures with radial access by centre ($P < 0.001$). KAP was higher by radial versus femoral access in low-radial-volume centres, and lower in high-radial-volume centres. Radiation protection techniques, such as the use of low frame rates (7.5 frame/s), were used more frequently in high-radial-volume radial centres.
Conclusions. — In this multicentre study, radial access was associated with lower radiation doses to patient than femoral access in high-radial-volume centres. Provided that radioprotection methods are implemented, radial access could be associated with lower patient radiation exposure.

MOTS CLÉS
Coronarographie ;
Angioplastie coronaire ;
Voie radiale ;
Produit dose-surface ;
Radioprotection

Résumé
Contexte. — La voie radiale est considérée comme plus irradiante pour les patients que la voie fémorale pour les coronarographies (CA) et les angioplasties coronaires (PCI)
Objectifs. — Cette étude a comparé l'exposition des patients lors de CA et PCI réalisées par voie radiale et fémorale.
Méthodes. — RAY'ACT est une étude française multicentrique évaluant l'exposition des patients aux rayons x lors des procédures de cardiologie interventionnelle coronaire, qui a analysé rétrospectivement les paramètres d'exposition pour 21 675 CA et 17 109 PCI réalisées dans 44 centres en 2010.

Résultats. — La voie radiale a été utilisée dans 71 % des CA et 69 % des PCI. Bien que le temps de scopie médian soit plus long pour la voie radiale versus fémorale (CA, 3,8 vs 3,5 minutes [$p < 0{,}001$] ; PCI, 10,4 vs 10,1 minutes [$p = 0{,}001$]), le produit dose-surface (KAP) était inférieur pour la voie radiale (CA, 26,8 vs 28,1 Gy·cm^2 ; PCI, 55,6 vs 59,4 Gy·cm^2 ; tous $p = 0{,}001$). Les différences de KAP restaient significatives en analyse multivariée ($p < 0{,}01$), et par analyse stratifiée sur un score de propension ($p = 0{,}01$). Une interaction significative a été observée entre le KAP et le pourcentage de procédures par voie radiale des centres ($p < 0{,}001$). Le KAP était plus élevé par la voie radiale vs fémorale dans les centres à faible volume pour la voie radiale, et inférieur dans les centres à haut volume pour cette voie. Les techniques de radioprotection, telles que les cadences faibles (7,5 images/s), étaient plus souvent utilisées dans les centres à haut volume pour la voie radiale.
Conclusions. — Dans cette étude multicentrique, la voie radiale était associée à une irradiation du patient inférieure à la voie fémorale, globalement et particulièrement dans les centres à haut volume de voie radiale. Sous réserve de la mise en place de méthodes de radioprotection, la voie radiale pourrait être associée à une irradiation du patient réduite.

Background

Since its introduction in 1989, radial arterial access has been used increasingly for coronary angiography (CA) and percutaneous coronary intervention (PCI) in many European countries [1] and, to a lesser extent, in the USA [2,3]. Transradial PCI has been associated with a lower bleeding risk and fewer access-site complications compared with femoral access [4]. In the setting of acute ST-segment elevation myocardial infarction, the radial route for primary PCI has been associated with improved survival [5]. However, unresolved issues related to the radial access remain, including radiation exposure [2,6]. Various studies suggest that transradial CA and PCI are associated with higher radiation doses compared with the femoral route, to both patients and staff [6—10]. Radiation dose can be modulated by the learning curve for transradial interventions [11,12], and the procedural volume of the operator [13] and centre [14]. Because reduction of radiation during cardiac procedures is mandatory [15], overexposure may be a limitation of radial access.

Patient's Exposure to X-Ray During Coronary Angiography and Percutaneous Transluminal Coronary Intervention (RAY'ACT) is a large, nationwide, multicentre survey aimed at evaluating practices in patient radiation protection in France, a country where the radial route is highly used. In a preliminary analysis, we identified factors associated with the between-centre differences in patient exposure [16]. Raw analyses found that the radial access was associated with lower radiation doses to the patient, and this result contrasted with others in a recent meta-analysis [8]. The purpose of the present study was to further analyse the relationship between radiation dose and arterial access, by comparing radial and femoral routes for variables related to patient exposure, and by testing the roles of the volume of the centre for radial access and the use of techniques for protection from radiation.

Methods

Study design

RAY'ACT-1 is a French, nationwide, investigator-driven, industry-independent, observational, retrospective study, conducted in 44 interventional cardiology centres in France [16]. Patient identities were preserved according to current ethical regulations. The study protocol was approved by national ethics committees and the institutional committee on human research, and subjects provided informed consent.

Data collection

Data from CAs and PCIs performed from 01 January to 31 December 2010 were collected from 44 centres using local software. For each procedure, the following data were collected: patient characteristics (sex, age, body mass index [BMI]); examination details, including arterial access (radial, femoral; the other brachial accesses such as humeral and ulnar were attributed to the radial group); and dosimetry indicators (Kerma-area product [KAP], fluoroscopy time, number of acquisition runs and number of frames) [17]. The radiological equipment comprised 48 cardiovascular X-ray imaging systems (four centres have two catheterisation laboratories, 40 centres have one catheterisation laboratory) from four different manufacturers, installed between 1998 and 2010, 79% of which had a flat panel detector. The choice of the arterial route was at the operator's discretion. Occupational dosimetry data, registered on separate computer systems with limited access, were not available.

Statistical analysis

Categorical variables are presented as counts and percentages, and were compared using the χ^2 test. Continuous data are presented as medians [interquartile ranges], and were compared using the non-parametric Mann-Whitney *U* test. Log-normally distributed continuous data, such as KAP and fluoroscopy time, were log-transformed for univariate and adjusted comparisons between radial and femoral routes by analysis of variance, and for linear correlation analyses.

Given the observational design of the study, and to minimize indication bias for arterial access, propensity score analyses were conducted. We estimated the propensity score of having a radial access, by fitting a logistic regression model using age, sex, BMI, emergency procedure and performance of left ventriculography as covariates. We then

Table 1 Baseline characteristics of patients and invasive procedures.

	Overall ($n = 55,704$)	Femoral access ($n = 16,920$)	Radial access ($n = 38,784$)	*P*
Patients				
Age (years)	67 [57—76]	68 [58—77]	66 [57—76]	< 0.001
Male	39,310/55,416 (71)	11,280/16,856 (67)	28,030/38,560 (73)	< 0.001
BMI (kg/m^2)	26.8 [24.3—30.0]	26.6 [24.0—29.7]	26.9 [24.2—30.1]	< 0.001
BMI $\geq$ 30 kg/m^2	12,276/48,889 (25)	3574/15,350 (23)	8702/33,539 (26)	< 0.001
Procedures				
CA	30,730/55,704 (55)	9055/16,920 (54)	21,675/38,784 (56)	
Ad-hoc PCI[a]	21,513/55,704 (39)	6372/16,920 (38)	15,141/38,784 (39)	
Elective PCI[b]	3461/55,704 (6)	1493/16,920 (9)	1968/38,784 (5)	< 0.001
Emergency	7175/52,208 (14)	2599/15,852 (16)	4576/36,356 (13)	< 0.001
Left ventriculography	12,372/25,445 (48)	4719/8926 (53)	7653/16,519 (46)	< 0.001
FFR	961/47,248 (2)	197/14,158 (1)	764/33,090 (2)	< 0.001
IVUS	353/47,215 (1)	89/14,152 (1)	264/33,063 (1)	0.11

Data are expressed as median [interquartile range] or *n*/*n* (%). BMI: body mass index; CA: coronary angiography; FFR: fractional flow reserve; IVUS: intravascular ultrasound; PCI: percutaneous coronary intervention.
[a] PCI immediately following coronary angiography in the same procedure.
[b] Planned PCI performed in a separate session.

matched the patients who underwent a procedure via radial access with those who had femoral access, by stratification into subsets based on the quintiles of the estimated propensity score. Patients who could not be matched using these criteria were removed from the analysis. Then, analyses of the association between the arterial access and patient exposure were repeated after matching within each propensity score stratum (13,655 CAs and 8816 PCIs).

To assess the role of centre volume of transradial procedures in the relationship between radial access and radiation dose, a term of interaction was introduced, and was tested in the multivariable linear model. Significance levels were adjusted for multiple comparisons using a conservative Bonferroni's correction. *P*-values were two-sided and were considered statistically significant at < 0.01. All statistical analyses were carried out with IBM SPSS Statistics, version 12.0 (SPSS Inc., Chicago, IL, USA).

Results

Baseline characteristics

Dosimetric data were obtained for 31,066 of the 33,931 CAs (92%), and for 25,356 of the 27,823 PCIs (91%) performed during 2010 in the 44 participating centres. Arterial access route was missing for 336 CAs and 382 PCIs, respectively. Therefore, among patients with dosimetric data and known arterial access route, radial access was used in 21,675/30,730 CAs (71%) and in 17,109/24,974 PCIs (69%), with significant differences across centres (the rate of radial access ranged from 1.7% to 94.1% for CA, and from 1.8% to 94.7% for PCI; both $P < 0.0001$). Right radial access was used in 33,005/38,784 transradial procedures (85%). Multiple arterial accesses were necessary in 2868/55,704 patients (5%) (Supplementary Table).

Baseline characteristics according to type of arterial access are shown in Table 1. Compared with femoral access, transradial access was performed in younger patients (66 vs 68 years), and more frequently in male (73% vs 67%) and obese (26% vs 23%) patients. Emergency procedures and left ventriculography were more frequent in transfemoral procedures. Among PCIs, elective PCI using the femoral access was more frequent (9% vs 5%; $P < 0.001$).

Radiation dose variables and arterial access

Variables related to the patient's radiation dose according to arterial access type are shown in Table 2. By univariate analysis, median fluoroscopy time was significantly higher in CAs and PCIs performed using radial versus femoral access (CA, 3.8 vs 3.5 minutes [$P < 0.001$]; PCI, 10.4 vs 10.1 minutes [$P = 0.001$]). In contrast, median KAP was significantly lower for radial versus femoral access (CA, 26.8 vs 28.1 Gy·cm^2; PCI: 55.6 vs 59.4 Gy·cm^2; both $P < 0.001$).

By multivariable regression analysis, age, sex, BMI, emergency procedure and left ventriculography were independently associated with arterial access (all $P < 0.001$). After adjusting for these factors, mean KAP remained significantly lower for radial versus femoral access (CA, 25.9 vs 27.0 Gy·cm^2 [$P = 0.002$]; PCI, 53.5 vs 56.4 Gy·cm^2 [$P < 0.001$]). Using the propensity-matched cohort, radial access was associated with lower KAP ($P = 0.012$ for CA and $P = 0.007$ for PCI). Similar findings were found when procedures with multiple arterial accesses were excluded (Table 3).

Effect of centre volume of radial access on radiation dose

By multivariable regression analysis controlling for age, sex, BMI, left ventriculography and emergency procedure, a significant association was found between KAP and the percentage of radial access in the centre ($P < 0.001$). Similar results were found when centres were split into tertiles for frequency of radial access. In centres in the highest tertile ($\geq$ 80% radial access), KAP was significantly lower than in the

Table 2 Patient radiation exposure with radial versus femoral access.

	CA			PCI		
	Femoral access ($n = 9055$)	Radial access ($n = 21,675$)	P[a]	Femoral access ($n = 7865$)	Radial access ($n = 17,109$)	P[a]
Univariate analysis						
KAP (Gy·cm^2)	28.1 [16.4—46.9]	26.8 [15.1—44.5]	< 0.001	59.4 [34.6—99.9]	55.6 [32.2—92.1]	< 0.001
Fluoroscopy time (minutes)	3.5 [2.1—6.5]	3.8 [2.3—6.3]	< 0.001	10.1 [6.2—16.7]	10.4 [6.9—16.0]	0.001
Number of frames	601 [432—846]	526 [360.5—727]	< 0.001	867 [599—1,245]	808 [560—1,143]	0.03
Number of runs	10 [8—13]	9 [8—12]	< 0.001	20 [15—27]	19 [14—26]	0.03
Contrast media volume (mL)	105 [75—140]	90 [68—120]	< 0.001	180 [130—246]	160 [115—220]	< 0.001
Multivariable analysis						
Mean KAP[b] (Gy·cm^2)	36.4 (35.5—37.2)	35.6 (34.9—36.2)	0.001	77.7 (75.5—79.9)	72.5 (70.9—74.2)	0.001

Data are expressed as median [interquartile range] or adjusted mean (95% confidence interval). BMI: body mass index; CA: coronary angiography; CI: confidence interval; KAP: Kerma-area product; PCI: percutaneous coronary intervention.
[a] Tests were performed on log-transformed values for variables following a log-normal distribution.
[b] Adjusted on patient's age, sex, BMI, emergency procedure and left ventriculography.

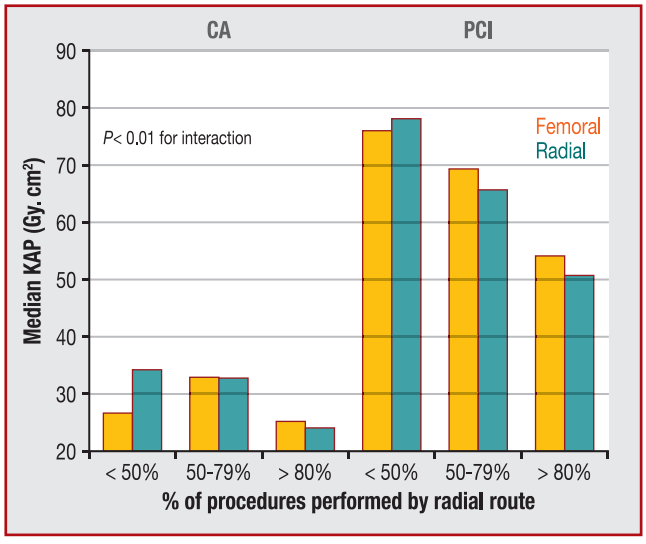

Figure 1. Radiation exposure according to tertiles of the percentage of procedures performed by the radial route. Radiation exposure decreased significantly in centres where a higher percentage of procedures were performed by the radial route. CA: coronary angiography; KAP: Kerma-area product; PCI: percutaneous coronary intervention.

middle (50—79%) and lowest (< 50%) tertiles, for both CA and PCI (Fig. 1). By the multivariable linear regression model, a significant interaction ($P < 0.001$) was found between the percentage of radial access in the centre, and the radial-femoral difference for KAP. As a result of this interaction, KAP was significantly higher by radial versus femoral access in low-radial-volume centres (CA, 34.2 vs 26.6 Gy·cm^2; PCI, 78.1 vs 76.1 Gy·cm^2; both $P < 0.01$), but significantly lower in high-radial-volume centres (CA, 24.1 vs 25.3 Gy·cm^2; PCI, 50.8 vs 54.2 Gy·cm^2; both $P < 0.01$) (Fig. 1). Fig. 2 shows the radial-femoral difference in median KAP for each of the 44 centres according to the percentage of radial access in the centre. This analysis confirmed a linear relationship between the radial-femoral difference in KAP and the rate of radial access in the centre (CA, $r = -0.68$; PCI, $r = -0.51$; both $P < 0.001$).

Radial access and radiation protection practices

Similarly to KAP, the number of frames was lower in transradial versus transfemoral CA, and borderline lower for PCI (Table 2). The differences between radial and femoral approaches were not totally explained by the differences in the number of acquisition runs and left ventriculography, as they remained significant ($P < 0.001$) after adjustment for these variables. Similarly to KAP, significantly lower median [interquartile range] numbers of frames were observed by radial versus femoral access in the subgroup of procedures without left ventriculography (CA, 455 [347—614] vs 533 [424—705] frames; PCI, 771 [541—1062] vs 893 [630—1286] frames; both $P < 0.001$). The use of very low frame rates by operators (7.5 vs > 7.5 frames/s) was more frequent in transradial versus transfemoral procedures (CA, 24% vs 16%; PCI, 27% vs 18%; both $P < 0.001$).

Discussion

In our observational study, radial arterial access was not associated with an increase in radiation dose to patients during CA or PCI. Rather, compared with the femoral approach, KAP was slightly but significantly lower by the radial approach, especially in centres with a high volume of transradial procedures. Previous comparative studies have shown conflicting results. A meta-analysis of observational and randomised studies demonstrated increased radiation exposure with radial access compared with femoral access [8]. Most of these were single-centre studies, performed in centres with low volumes of radial access or during the learning phase for this route. More recent studies did not find significant radial-femoral difference in patient exposure, after controlling for clinical or procedural cofounders,

Table 3 Radiation dose in procedures performed by single arterial access and multiple arterial access.

	Single arterial access			Multiple arterial access		
	Femoral access	Radial access	*P* (RA vs FA)[a]	Femoral first	Radial first	All conversions
CA (*n*)	8637	20 454		418	1221	1639
KAP (Gy·cm^2)	27.7 [16.1—45.9]	26.2 [14.9—43.2]	< 0.001	31.6 [19.3—53.1]	38.2 [21.0—61.0]	35.9 [20.5—58.0]
Fluoroscopy time (minutes)	3.4 [2.0—6.4]	3.7 [2.3—6.1]	0.001	3.8 [2.4—7.4]	4.9 [3.2—8.6]	4.5 [2.9—8.2]
Number of frames	545 [409—776]	520 [352—727]	< 0.001	777 [585—969]	544 [399—730]	665 [468—880]
Number of runs	10.0 [8.0—12.0]	9.0 [8.0—11.0]	< 0.001	11.0 [9.0—14.0]	10.0 [9.0—12.0]	10.0 [8.0—13.0]
Mean KAP[b]	35.7 (34.8—36.6)	34.4 (33.8—35.1)	< 0.001	—	—	—
PCI (*n*)	7479	16 266		386	843	1229
KAP (Gy·cm^2)	57.9 [33.8—96.7]	54.3 [31.6—89.4]	< 0.001	72.1 [40.7—128.2]	83.7 [44.1—140.6]	78.9 [42.5—133.9]
Fluoroscopy time (minutes)	9.7 [6.0—16.0]	10.2 [6.8—15.6]	< 0.001	14.2 [9.3—23.6]	14.0 [9.2—22.4]	14.0 [9.3—23.0]
Number of frames	793 [556—1104]	796 [546—1152]	0.01	1232 [905—1637]	860 [628—1133]	1073 [748—1477]
Number of runs	18.0 [14.0—25.0]	19.0 [14.0—25.0]	0.02	25.0 [19.0—33.0]	20.0 [16.0—28.0]	23.0 [17.0—31.0]
Mean KAP[b]	77.9 (75.6—80.1)	70.7 (69.0—72.4)	< 0.001	—	—	—

Data are expressed as median [interquartile range] or adjusted mean (95% confidence interval). CA: coronary angiography; FA: femoral access; KAP: Kerma-area product (or dose-area product); PCI: percutaneous coronary intervention; RA: radial access.

[a] Tests were performed on log-transformed values for variables following a log-normal distribution.

[b] Adjusted on patient's age, sex, body mass index, emergency procedure and left ventriculography.

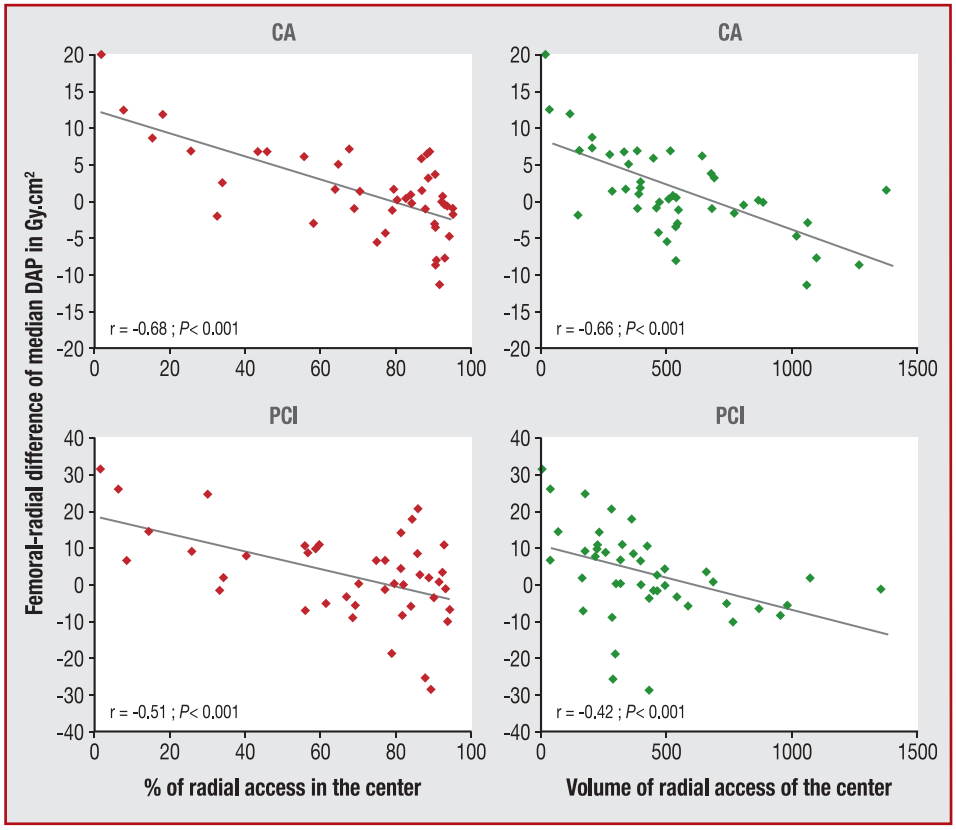

Figure 2. Radial-femoral difference in radiation exposure according to the percentage of procedures performed by the radial route in each centre. The radial-femoral radiation exposure difference was positive in low-radial-volume centres, but negative in high-radial-volume centres. CA: coronary angiography; KAP: Kerma-area product; PCI: percutaneous coronary intervention.

and for procedural complexity in PCI [18–21], while other studies were in favour of radial access [22].

The first clinical implication of this study is that it confirms, in a multicentre setting and in a country where radial access is common, that exposure with radial access is modulated by the volume of transradial procedures. The learning curve, the experience and the high volume of operators for radial access have been underlined as key factors in radiation dose reduction [12–14,18]. In the Radlal Versus femorAL (RIVAL) randomised trial [13], KAP was not significantly different between radial and femoral access, while fluoroscopy time and the radiation dose (measured by the total air Kerma calculated at the interventional reference point) were higher in transradial procedures. When results were stratified by procedural volume, variables of exposure only increased in the lowest tertile of radial volume centres, with a significant interaction for total air Kerma [13]. In a recent multicentre observational study [14], transradial access was associated with a modest increase in patient radiation exposure, but exposure was equivalent when a centre's balance of transradial and transfemoral procedures approached 50%. Our results extend these findings. We found an inversion, not only a reduction, of the radial-femoral difference for KAP according to the radial volume of the centre, with a significant interaction or as a continuous variable with a linear relationship.

The second major clinical implication is the likely role of the implementation of radiation protection techniques in high-radial-volume centres. Our results, like others [7,11,19,20], showed a small but significant increase in fluoroscopy time in transradial CA and PCI. The reduction in KAP by radial access is therefore not explained by the fluoroscopy time, and it is mainly driven by a significant reduction in the number of frames. Number of frames is a composite variable that may depend on the number of acquisition runs, including those related to left ventriculography, the length of the runs and the frame rate (7.5, 10, or >10 frames/s) during image acquisition.

Left ventriculography, which is classically associated with a 15–30% increase in radiation dose [22,23], was more frequent in transfemoral procedures. The lower median numbers of runs during CA, and volume of contrast media in CA and PCI by radial access, suggested that the performance of left ventriculography may be a confounder for the difference in KAP between the femoral and radial routes. This hypothesis was not confirmed by multivariable analysis and after propensity score matching, and the differences between access-site approaches for KAP were consistent in procedures performed without left ventriculography.

In contrast, the use of low frame rates (7.5 frames/s) was more frequent in high-radial-volume centres than in low-radial-volume centres. Therefore, we might hypothesise that because radial access has been initially associated with an increase in radiation dose to patients and staff, operators and centres with a high volume of radial access may have implemented more techniques aimed at reducing exposure than operators or centres mainly using the femoral access. The significant reduction in KAP in transradial procedures

found in high-radial-volume centres may indicate better practices in protection from radiation, including the routine use of low frame rates. This hypothesis is supported by the overall significant decrease in KAP according to the radial volume of the centre, demonstrated regardless of the arterial access. The present results, beyond the effect of radial versus femoral access by itself, suggest that centres and operators accustomed to the radial route implemented techniques for limiting radiation exposure on a wider scale, while centres using predominantly the femoral route may have stuck to a more conservative approach.

Study limitations

Some limitations of our study should be taken into consideration. First, although it was prospectively designed, collection of data was retrospective, and arterial access was not randomised. This resulted in baseline differences between groups that may have affected the results, despite the fact that comparisons were adjusted for age, sex, BMI, emergency procedure and left ventriculography, and that the propensity score included these confounders. A selection bias remains possible, and the operators may have chosen more complex patients (unstable patients, those with cardiogenic shock, the elderly) for the femoral approach. However, this putative bias is most likely to affect the radial versus femoral comparison for PCI, and to a lesser extent for diagnostic CA alone. In the present study, the differences between arterial routes were homogeneous, regardless of the category of procedure (diagnostic or therapeutic), the emergency and the age and clinical status of the patient. Also, this study analysed the radial volume of centres, not of individual operators. However, operators who worked in more than one centre were rare in the present study. Finally, the study did not aim to analyse occupational exposure, and operators' dosimetry data, which are stored on different secure computer systems, were not available.

Conclusions

In this large multicentre study, radial access was associated with lower radiation doses to patients than femoral access during CA and PCI. The difference remained in a propensity-matched cohort analysis. Differences in patient exposure between radial and femoral access were associated with the radial volume of the centre, and with variables that probably reflect the centre's radiation protection practices. Provided that radioprotection methods are implemented, radial access could be associated with lower patient radiation exposure.

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Disclosure of interest

The authors declare that they have no competing interest.

Appendix A.

RAY'ACT-1 study sites and participating investigators

Aix en Provence: CH du Pays d'Aix (Bernard Jouve, Annick Bourdeloie, Claude Barnay); Angoulême: CH Général Girac-Angoulême (Nicolas Lucke, Véronique Lucke); Annecy: CH de la Région d'Annecy (Lionel Mangin, Henri Bonnet, Stéphane Fol, Loïc Belle); Argenteuil: CH Victor-Dupouy (Thierry Carreres, François Duclos, Chloé Durier, Toufik Bouzazoua); Aulnay sous Bois: CH Intercommunal Robert-Ballanger (Jean-Michel Montely); Auxerre: CH d'Auxerre (François-Xavier Soto, Frédéric Schaad); Avignon: CH Henri-Duffaut (Jean-Lou Hirsh, Michel Pansieri, Edith Larderet); Boulogne-sur-Mer: CH du Docteur-Duchêne (Olivier Nugue); Bourges: CH Jacques-Cœur (Thierry Déchery, Pierre Marcollet, Xavier Tabone); Brive: CH de Brive (Jean Paul Faure, Eric Fleurant); Cannes: CH de Cannes (Thierry Tibi, Gilles Zemmour); Chartres: Hôpital Louis-Pasteur (Franck Albert, Christophe Thuaire, Christophe Laure, Grégoire Range); Colmar: Hôpital Albert-Schweitzer (Laszlo Levai, Michel Schneeberger, Antoine Verdun, Hervé Faltot); Compiègne: CH Général de Compiègne (Jérôme Clerc, Anne Luycx-Bore); Corbeil-Essonnes: CH Sud-Francilien Hôpital Gilles-de-Corbeil (Pascal Goube, Romain Berthier, Marcel Toussaint); Dunkerque: CH de Dunkerque (Olivier Tricot, Steve Werquin); Eaubonne: CH Intercommunal Eaubonne-Montmorency Hôpital Simone-Veil (Gaëtan Karrillon, Abdel Akesbi); Gonesse: CH de Gonesse (Mohamed Ghannem, Pierre Aubry, Serge Godard); Haguenau: CH de Haguenau (Pierre Leddet, Fabien de Poli, Philippe Couppie, Michel Hanssen); La Roche Sur Yon: CH Départemental Les Oudairies (Laurent Orion); La Rochelle: CH Saint-Louis (Laurent Ledain, Ludovic Meunier, Yann Valy, Paul Bru); Lagny-sur-Marne: CH de Lagny-Marne-la-Vallée (Simon Elhadad); Le Mans: CH du Mans (Dr François Vinchon, Thierry Labbé, Philippe Rosak); Lens: CH du Docteur-Schaffner (Valérie Aumegeat, Mohamed Elmoujahid, Claudie Vandewalle, Max Pecheux); Libourne: CH Robert-Boulin (Jean-Marie Perron, Jérome Lefevre); Lorient: CH Bretagne-Sud (Pierre Cazaux, Jean-Philippe Hacot, Pierre Khattar, Serge Baleynaud); Le Plessis-Robinson: Centre Chirurgical Marie-Lannelongue (Christophe Caussin, Saïd Ghostine, Nicolas Amabile); Metz: CH Régional Notre-Dame de Bon Secours (Khalifé Khalifé, Michel Boursier, Marwan Yassine); Montfermeil: CH Intercommunal Le Raincy-Montfermeil (Olivier Nallet, Jean-Baptiste Estève, Simon Cattan); Mulhouse: CH Emile-Müller (Laurent Jacquemin, Olivier Roth, Jean-Yves Wiedemann); Nevers: Hôpital Pierre-Bérégovoy (Jacques Ballout); Paris: Hôpital d'Instruction des Armées du Val De Grâce (Jacques Monsegu, Patrick Schiano, Franck

Barbou); Paris: Institut Mutualiste Montsouris (Alain Dibie); Poissy: CH Intercommunal de Poissy-Saint-Germain (Xavier Marchand, Dina Zannier, David Berville); Pontoise: CH René-Dubos (François Funck, Nils Guillard, Véronique Decalf); Quimper: CH Intercommunal de Cornouaille (Gilles Rouault, Daniel Garnier, Thierry Joseph, Jacques Dewilde); Saint-Brieuc: CH Yves Le Foll (Benoit Moquet); Saint-Laurent du Var: Institut Arnaud Tzank (Pierre Meyer); Saint-Malo: CH de Saint-Malo (Philippe Deutsch, Antoine Rialan); Saint-Nazaire: CH Général de Saint-Nazaire (Loïc Genet, Jacques Denis), Polyclinique de l'Europe (Yann Chalet); Saint-Quentin: CH Général de Saint-Quentin (Sébastien Duval, Sandie Spagnol, Eric Colpart); Suresnes: Hôpital Foch (Hakim Benamer); Valence: CH de Valence (Philippe Chapon); Valenciennes: CH Jean-Bernard (Didier Vilarem); Vannes: CH Bretagne-Atlantique (Emmanuelle Filippi-Codaccioni, Alain Kermarrec, Christophe Le Ray); Versailles-Le Chesnay: CH de Versailles, Hôpital André-Mignot (Jean-Louis Georges, Géraldine Gibault-Genty, Bernard Livarek); Vichy-Moulins: CH Général de Vichy (Xavier Marcaggi, Martin Hevin); Villeneuve-St-Georges: CH Intercommunal de Villeneuve-St-Georges (Dominique Dumant, Pascal Wyart).

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.acvd.2016.09.002.

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