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Analysis of Factors Affecting Air Kerma Area Product Obtained during Uterine Artery Embolization Procedures Using Logistic Regression

Khaled Soliman[1] Ahmed Almutairi[2] Murdhi AlHarbi[2] Khaleel Almutairi[2] Turky Almutairi[2] Mousa Bakkari[1]

[1]Department of Medical Physics, Prince Sultan Military Medical City, Riyadh, Saudi Arabia
[2]Department of Radiodiagnostic and Medical Imaging, Prince Sultan Military Medical City, Riyadh, Saudi Arabia

Address for correspondence Khaled Soliman, PhD, DABMP, Department of Medical Physics, Prince Sultan Military Medical City, P. O. Box 7897 (B-94), Riyadh 11159, Saudi Arabia (e-mail: khaledsoliman61@gmail.com).

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Abstract

Purpose Uterine artery embolization (UAE) is a common interventional radiology procedure used in medicine; the procedure is safe but there is always a concern regarding radiation dose received by the patient. The aim of this study was to use multivariable logistic regression analysis (MLRA) to study a certain number of independent prognostic variables believed to provide an estimate of the likelihood of obtaining a high kerma area product (P_{KA}) at the end of the procedure.

Method Radiation dose indices registered by the angiographic system structured dose report, the total fluoroscopy time (FT), the patient' body mass index (BMI), the number of images taken during the procedures (IMGS), and the performing physician experience (EXPER) were used to drive a logistic regression model (LRM).

Results The LRM found was: Logit (P_{KA}) = −6.1525 + 0.0416 (FT) + 0.1028 (IMGS) + 0.1675 (BMI) – 0.1012 (EXPER). The prediction accuracy of the LRM was assessed using receiver operating characteristic (ROC) curve; by calculating the area under the curve (AUC), we found AUC = 0.7896, with optimal ROC point of 0.3261, 0.8036.

Conclusion The suggested LRM seems to indicate that patients with higher BMI, have taken longer FT, acquired higher IMGS and the procedure done by a less experienced performing physician is more susceptible to receive a higher P_{KA} at the end. The proposed LRM is useful in predicting the occurrence of higher radiation exposure interventions and can be used in patients' radiation dose optimization strategies during UAE procedures.

Keywords
- air kerma
- logistic regression
- predictive variables
- uterine artery embolization
- radiation dose

Introduction

Uterine artery embolization (UAE) is a minimal invasive procedure that requires fluoroscopic and angiographic imaging and this causes a concern regarding the radiation dose received by the patient during the intervention. It is known that angiographic imaging systems can deliver a significant amount of radiation to the patient's skin; therefore, radiation dose monitoring is required.[1] We have reviewed the radiation dose metrics available from the angiographic system for 102 UAE procedures performed on the system during the past year 2019. Along with the dosimetric metrics we have

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also included the body mass index (BMI) and the interventional radiologist experience (EXPER) to the variables that will be analyzed.

Multivariable logistic regression (MLR) analysis has been widely used as a method to identify prognostic factors affecting medical treatments outcome.[2] The aim of this study was to analyze radiation dose-related metrics available from the angiographic system and from the radiology information system (RIS) and to use MLR to estimate the occurrence of high radiation dose procedures.

Methods

Patient Characteristics

In this study we have retrospectively collected from the angiographic system registered dose report and from the (RIS) data concerning 102 patients who underwent UAE procedures in 2019. Radiation dose indicators such as, the fluoroscopy time (FT) in minutes, the cumulative kerma area product (P_{KA}) in Gy cm², the cumulative reference air kerma ($K_{a,r}$) in mGy, the number of images taken during the procedure (IMGS), and the calculated patient body mass index (BMI) were collected. We also noted for each patient the experience of the performing physician in the form of total number of performed UAE procedures in the variable (EXPER). ►**Table 1** has the summary of the patients' data used in this work. This retrospective study was approved by the institution's research ethics committee.

Imaging Equipment

We used a biplane system C-arm with flat detector angiography, AXIOM Artis dBA (Siemens, Erlangen, Germany).

Logistic Regression Analysis

A binary logistic regression model (LRM) was calculated using variables that may predict the level of cumulated P_{KA} at the end of the procedure. It is known that P_{KA} is related to the risk of exposure to radiation.

P_{KA} is the binary outcome variable used in the analysis. High P_{KA} levels are assigned the value of 1 and routine P_{KA} levels will be assigned the value 0. The LRM will have the following form:

$$Y = \ln(\text{odds [event]}) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots\ldots\ldots + \beta_n x_n \quad (1)$$

In Eq. (1) the variable Y is log (naturel) of the odds of the event under consideration. In our case the event will be the occurrence of high P_{KA} procedure. The βs are the coefficients of the regression calculated by the model and n is the number of predictive variables. The odds ratios are the exponential of the coefficients and will be given by:

$$\text{Odds ratios} = \text{Exp}(\beta) \quad (2)$$

Statistical Analysis

The DAP values for 102 patients were dichotomized into two groups >300 Gy cm² and ≤300 Gy cm², the first group is considered as high radiation dose procedure (HRDP) and the second as routine radiation dose procedure.

The choice of 300 Gy cm² was based on the American Society of Vascular Interventional Radiology.[3] They recommended alert levels to be displayed on the Angiographic system during the procedure, as to alert the surgeon that a DAP value of 300 Gy cm² has been reached. Furthermore 300 Gy cm² is considered an appropriate indicator for substantial radiation dose levels for most interventional radiology procedures.[4]

One of the objectives of this study was to identify the independent variables which are able to estimate HRDP group during UAE and to propose a LRM for the prediction of HRDP.

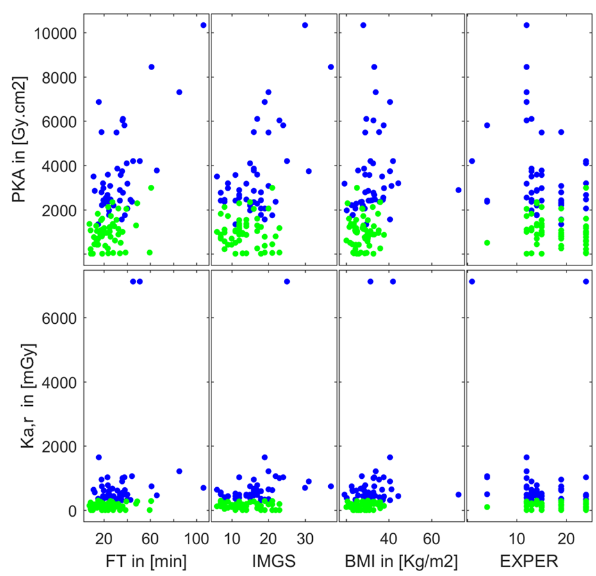

Fig. 1 Scatter plots matrix showing $K_{a,r}$ and P_{KA} as function of FT, IMGS, BMI, and EXPER, respectively. The dark blue dots are for the procedures with P_{KA} >300 Gy cm² and the light green dot for procedures with P_{KA} ≤300 Gy cm². BMI, body mass index; FT, fluoroscopy time; EXPER, experience; IMGS, images.

Table 1 Summary of 102 patients' data and their associated radiation dose metrics

	FT (min)	IMGS	BMI (kg/m²)	EXPER	P_{KA} (Gy cm²)	$K_{a,r}$ (mGy)
Mean	28	14.9	30.0	16.5	480	2,140
Minimum	7.3	6.0	19.3	1	0.46	9.14
Maximum	105.9	37	72.6	24	7,125	10,340
Standard deviation	15.7	5.8	6.9	5.3	991	1,882
Coefficient of variation	0.56	0.39	0.23	0.32	2.06	0.88

BMI, body mass index; FT, fluoroscopy time; EXPER, experience; IMGS, images.

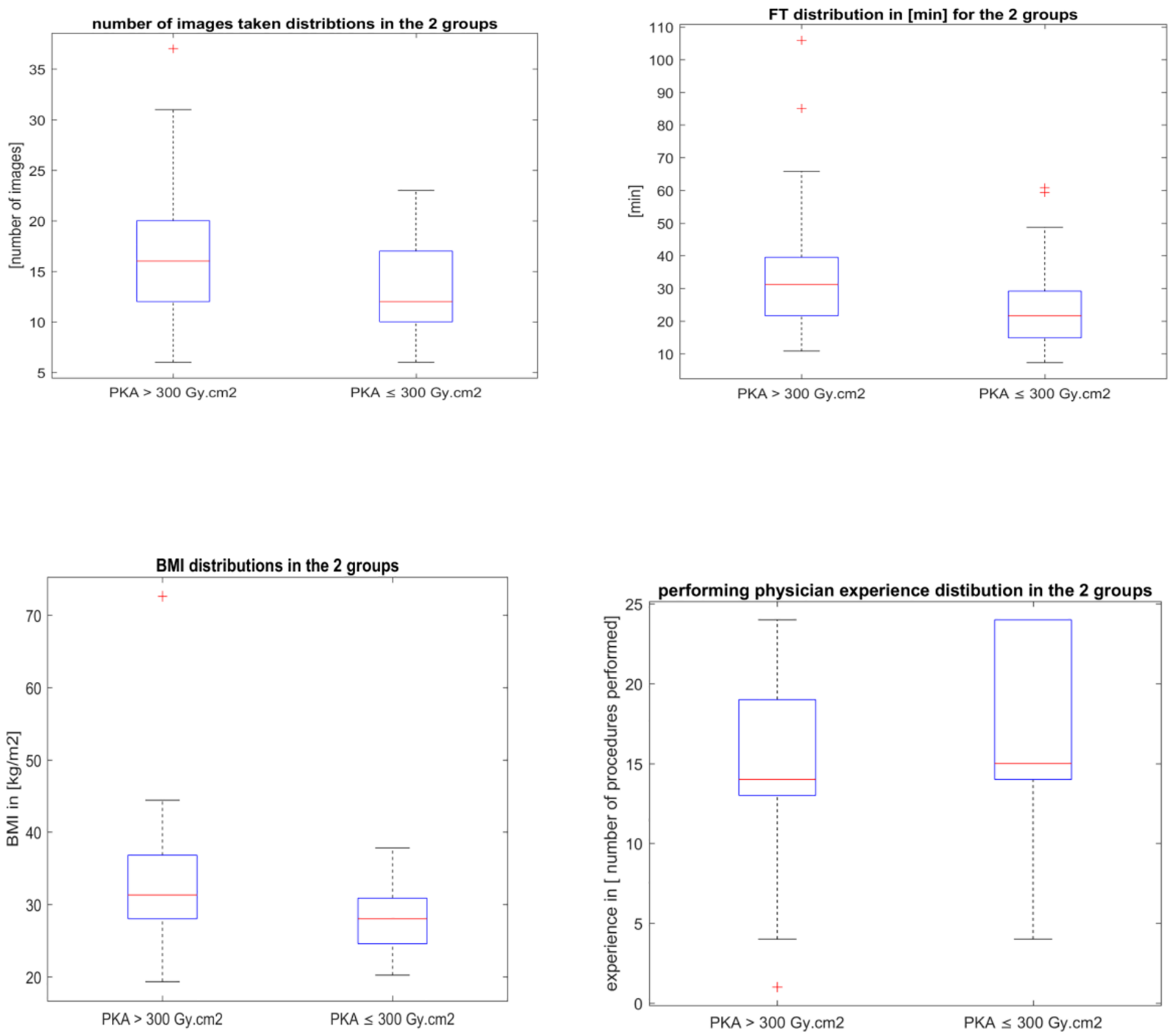

Fig. 2 Boxplots showing the four predicting variables distribution for the two dependent variable categories: P_{KA} >300 Gy cm^2 and P_{KA} ≤300 Gy cm^2.

►**Fig. 2** is showing the data distribution in the form of boxplots.

The statistical analysis was performed using Matlab (R2016b) statistics and machine learning toolbox (Natick, United States). A *p*-value of (<0.05) was considered statistically significant.

Results

As expected, a linear regression relationship was found between the cumulative air kerma measured at the reference point ($K_{a,r}$) and the cumulated kerma area product (P_{KA}), therefore $K_{a,r}$ was excluded from the list of the predicting independent variables. Fig. 1 contains scatter plot matrix of the Ka,r and *PKA* as function of FT, IMGS, BMI, and EXPER variables.

Binary Logistic Regression Model

The degree of significance of four variables: FT, IMGS, BMI, and EXPER was examined. ►**Table 2** has the summary of the results. The obtained LRM with four predictors (variables) FT, IMGS, BMI and EXPER is given by the Eq. (3) below:

$$\text{Logit}\,(P_{KA}) = -6.1525 + 0.0416\,(\text{FT}) + 0.1028\,(\text{IMGS}) + 0.1675\,(\text{BMI}) - 0.1012\,(\text{EXPER}) \quad (3)$$

These results show that an increase of one unit of FT (1 minute) will have an increase of 4.16% in the cumulative P_{KA}, similarly an increase of one unit in the number of images taken will have an increase of 10.2% in the P_{KA} value, an increase of 1 unit in the BMI (1 kg/m^2) will have an increase of 16.75% in the cumulative P_{KA} and an increase of 1 unit in the variable EXPER will have a decrease in the total P_{KA} value by 10.12%; this variable is working in the advantage of lower P_{KA} value as opposed to the other three variables that all working in the advantage of obtaining a larger P_{KA} value.

The model was tested for goodness of fit with the DAP data using the area (AUC) under the ROC. The AUC was equal to 0.7896 with optimal ROC point coordinate of (0.3261,

Table 2 Results of the multivariable logistic regression analysis for all the variables that may be related to the occurrence of high radiation exposure UAE procedure

p-Value	OR (95% CI)	OR	*B*	Variables
0.0014			6.1525	Intercept
0.0508	(1.000–1.087)	1.042	0.0416	FT
0.0643	(0.994–1.236)	1.108	0.1028	IMGS
0.0008	(1.072–1.304)	1.182	0.1675	BMI
0.0485	(0.817–0.999)	0.904	0.1012	EXPER

Abbreviations: *B*, regression coefficients; OR, odds ratio; *p*, the *p*-value.

Table 3 Some of the reported PKA in the literature

Author	Year	P_{KA} (Gy cm^2)	$K_{a,r}$ (Gy)	*n*
Miller et al	2009	392	2.5	90
Vano et al	2009	236		
Ruiz-Cruces et al	2016	214		56
Durrani et al	2016	437 (267)[a]		
Kohlbrenner et al	2017	438 (175)[a]		
Schernthaner et al	2018	527 (146)[a]		
This study	2020	347	2.1	100

[a]The values in parentheses are the values obtained after applying imaging system optimization.

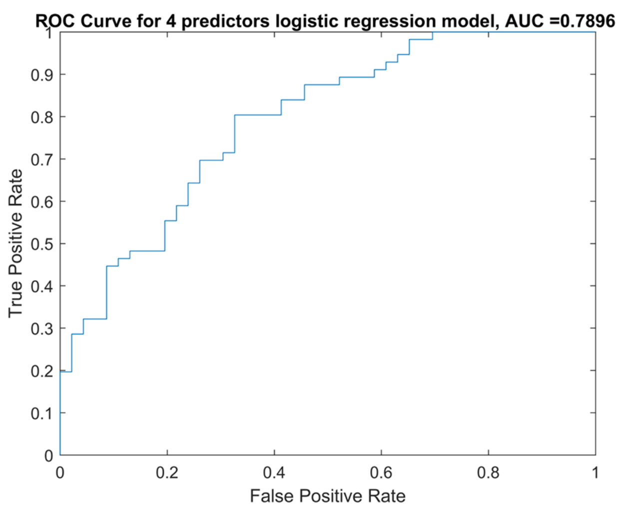

Fig. 3 The ROC curve for the proposed four predicative variables logistic regression model. ROC, receiver operating characteristic.

0.8036). ►**Fig. 3** shows the ROC for the four variables predictive model. The optimal ROC point seems to indicate a false positive rate of 32.6% and a true positive rate of 70.3% for the predictive model obtained.

Discussion

Comparing radiation dose values and dosimetric quantities among published studies is very difficult because the procedures identification are not standardized and also their complexity varies considerably and there is no classification for procedures in accordance with their respective complexity level yet.[5] Therefore there is always a need to perform regular local clinical dose audits. In this work we have analyzed available patient dose-related metrics with the aim of identifying the metrics or variables that affect the patient radiation exposure the most represented by the kerma area product during UAE.

Kerma Area Products during UAE

There are several published studies reporting radiation dose assessments and dose reduction and optimization techniques.[6-11] The reported values of P_{KA} are in ►**Table 3**. In this study we have found a median P_{KA} value of 347 Gy cm^2 for 102 UAE procedures conducted in 2019.

Suggested Reference Levels

The recommended dose reference level (DRL) for UAE was set at 450 Gy cm^2 and the reported 75th percentile P_{KA} from the radiation doses in interventional radiology procedures study (RAD-IR) data was 392 Gy cm^2.[6]

Procedures with DAP values above 300 Gy cm^2 should be optimized if possible. A recent study suggests using a DAP value of 50 Gy cm^2 as target value for UAE procedures. In this study the authors suggested strategies for reducing radiation exposure during UAE; the strategies included: optimized source image and object image distances, avoidance of magnification, use of tight collimation, use of road-mapping, avoidance of oblique projections, use of pulsed fluoroscopy with low images per second, use of low frame rates, use of last-image-hold, and avoid three-dimensional rotational angiography.[12]

The use of optimization strategies will reduce the radiation dose received by the patients as well as the staff performing the procedure especially in cases expected to lead to a higher than usual radiation dose like for obese patients.[13]

A recent study had concluded that during UAE procedures, BMI had the greatest impact on the cumulated $K_{a,r}$ and has a substantial impact on the risk of radiation-induced skin injury even without prolonged FT.[14]

Performing Physician Experience

The effect of interventional radiologist experience on FT and $K_{a,r}$ was studied, and the conclusion was: although there was no nonsignificant trend for shorter screening times with experience, technical success and safety were not compromised with appropriate consultant supervision, which illustrates a safe construct for IR training. This is important and reassuring information for patients undergoing a procedure in a training unit.[15]

This conclusion is not in agreement with this study since we have found a statistically significant correlation between the operator experience and the reported P_{KA} ($p = 0.0485$).

Complexity Level of the Procedure

Another study suggested after analyzing 56 UAE procedures, to include procedure complexity levels to facilitate clinical audits and proper use of DRLs in terms of P_{KA} for patient dose optimization in interventional radiology. They recommend DRLs of 167, 214, and 613 Gy cm^2 for simple, medium, and complex index UAE procedures, respectively. Statistical analyses (r Pearson and ANOVA test) identified significant correlations between the complexity score and patient dose (KAP) for all of the procedures ($F < 0.05$).[8]

Limitations

This retrospective study analyzed data from one medical center during 1 year and included 102 patients; the study was on one imaging system only. The study did not include information about the complexity level of the procedure. The level of complexity was reported in the literature to have an effect on the DRLs. Expanding the study to include more than one imaging system, multiple medical centers, and procedure complexity level, when possible, will improve the accuracy of the proposed predictive LRM. Furthermore, a follow-up study aiming at validating the proposed model using other patients' data is recommended.

Conclusion

In conclusion, the results of this retrospective study suggest that a UAE procedure having a cumulative DAP higher than 300 Gy cm^2 is likely to occur in procedures having patients with higher BMI values, have taken longer FT, acquired higher IMGS, and were accomplished by a less experienced performing physician.

The proposed LRM is useful in predicting the occurrence of higher radiation exposure interventions and can be used in patients' radiation dose optimization strategies during UAE procedures.

Funding
None.

Conflict of Interest
None declared.

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