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Radiation exposure during neurointerventional procedures in modern angiographic systems: A single center experience

Izloženost radijaciji tokom neurointerventnih procedura u modernim angiografskim sistemima: iskustvo jednog centra

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Abstract

Background/Aim. Interventional neuroradiology procedures expose patients to ionizing radiation. The aim of this study was to assess doses received by patients during interventional neuroradiology procedures and to establish dose range with an estimate of risk from adverse consequences of irradiation. **Methods.** Our study describes series of patients submitted to diagnostic and/or therapeutic procedures at the Department of Interventional Neuroradiology, Clinical Center Kragujevac, Serbia, from December 1, 2014 to December 1, 2016. The following variables were considered for this study: kerma-area product, air kerma and fluoroscopy exposure time; peak skin dose and effective dose calculated from the kerma-area product. **Results.** Median kerma-area product was 87.802 Gy·cm², 78.567 Gy·cm², 117.626 Gy·cm²; effective dose was 12.731 mSv, 11.392 mSv, 17.056 mSv; peak skin dose was 0.456 Gy, 0.409 Gy, 0.612 Gy, and estimated brain dose was 254.62 mGy, 227.84 mGy, 341.12 mGy, for diagnostic, therapeutic and combined procedures, respectively. **Conclusion.** Interventional neuroradiology procedures show significant variability in radiation dose, due to patient constitution, radiologist expertise and equipment factors. Knowing the doses can have a great benefit for patients and medical and paramedical stff in terms of prevention of possible deterministic and stochastic effects of the radiation.

Key words:
dose-response relationship, radiation; neuroradiography; radiation dosage; radiation protection.

Apstrakt

Uvod/Cilj. U toku interventnih neuroradioloških procedura bolesnici su izloženi jonizujućem zračenju. Cilj ove studije bio je da utvrdi doze jonizujućeg zračenja koje bolesnik primi tokom interventnih neuroradioloških procedura i proceni rizik od negativnih efekata i posledica jonizujućeg zračenja. **Metode.** Studijom su obuhvaćeni svi bolesnici kojima su urađene dijagnostičke i/ili terapijske procedure na Odseku interventne neuroradiologije u Kliničkom centru Kragujevac, Srbija, u periodu 1.12.2014–1.12.2016. godine. Beležene su sledeće vrednosti: *kerma-area product*; *air kerma*; vreme izloženosti jonizujućem zračenju; maksimamalna kožna doza i efektivna doza. **Rezultati.** Srednja vrednost *kerma-area product*-a iznosila je 87,802 Gy·cm², 78,567 Gy·cm², 117,626 Gy·cm²; efektivne doze 12,731 mSv, 11,392 mSv, 17,056 mSv; maksimalne kožne doze 0,456 Gy, 0,409 Gy, 0,612 Gy i procenjene doze za mozak 254,62 mGy, 227,84 mGy, 341,12 mGy, za dijagnostičke, terapijske i kombinovane procedure, redom. **Zaključak.** Interventne neuroradiološke procedure pokazuju izrazitu varijabilnost u emitovanoj i primljenoj dozi zračenja, u zavisnosti od konstitucije bolesnika, opreme, kao i iskustva radiologa. Poznavanje veličine ovih doza u različitim uslovima, može biti od velike koristi za bolesnike, kao i za medicinsko i paramedicinskog osoblje u smislu smanjenja mogućih determinističkih i stohastičkih efekata zračenja.

Ključne reči:
zračenje, odnos doza-reakcija; neuroradiografija; zračenje, doziranje; zračenje, zaštita.

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Introduction

Interventional neuroradiology (INR) procedures are guided by imaging techniques and both are performed as diagnostic and/or therapeutic [1]. Their use show constant increase, because of the great benefit they have for patients [2]. However, INR procedures expose patients to ionizing radiation [3]. The radiation risk is presented as deterministic effect, which happens after exceeding a radiation dose threshold, and stochastic effect, which does not have a threshold [4, 5]. Despite technological improvements, there are other risk factors such as procedure complications, longer time of fluoroscopy and high dose rates, which contribute to increase of the skin injuries and to occurrence of stochastic effects such as carcinoma [3–6]. Units that are provided by the INR angiographic system are kerma-area product (KAP) historically known as dose-area product, air kerma (AK) and fluoroscopy time (T) [7]. Since none of them is directly related to the patient organ doses, it is necessary to estimate the peak-skin dose (PSD) and effective dose (ED), which are associated with deterministic and stochastic effects, respectively [8–10].

The International Commission on Radiologic Protection (ICRP) proposed that the threshold for dose absorbed by patients' brain should be 0.5 Gy [11, 12]. It was also suggested that high doses could be avoided by real-time observation of doses by INR specialists, following proper consultation to their patients and optimization of risk factors [13]. Still, there are practical limitations to the direct measurement, such as inconvenient dosimeters [14]. Because of that, indirect assessment of radiation doses is currently used in a form of a KAP meter [15]. KAP does not supply us with direct radiation risk effect, but can be used to create dose reference level, together with AK and T [14, 16]. Dose reference levels are usually set at 75% and are defined as a degree of radiation exposure which should not be surpassed during procedures [14]. KAP can also be used to estimate the effect of ionizing radiation on patients, by calculating ED and PSD [17]. Previously published study has shown that for cerebral embolization, the average brain dose was 500 mGy and third quartile was 856 mGy, while for cerebral angiography, the average brain dose was 100 mGy [11]. That study did not show the exact formula or conversion factor from KAP to ED, but cite the website with formula that was used for calculation [18].

There is little information available regarding patient exposure to the radiation during INR procedures. Most of studies that were already published were conducted on patients subjected to cardiac and other vascular procedures, or showed variations in number of patients and dose calculations [8–10, 14, 17, 19, 20]. To our knowledge, there is limited data on radiation indicators during INR procedures and especially on brain doses. Accordingly, the aim of this study was to assess doses received by patients during INR procedures and to establish INR dose range with an estimate of risk from adverse consequences of irradiation.

Methods

Our study describes series of patients submitted to diagnostic and/or therapeutic procedures at the Department of Interventional Neuroradiology, Clinical Center Kragujevac, Serbia, from December 1, 2014 to December 1, 2016. The study was approved by our Institutional Ethics Committee. Data used in the study were collected from the angiographic database.

We included all patients who underwent diagnostic procedures (cerebral angiographies) and therapeutic INR procedures: aneurism embolizations and embolizations of arteriovenous malformations (AVM). Follow-up diagnostic procedures, after therapeutic ones, were excluded. All procedures were performed by a team of two experienced interventional neuroradiologists. Both of radiologists had performed over 1,000 aneurysm and AVM embolizations and had over 10 years of experience.

The angiographic system used was a biplane angiographic unit (Allura Xper FD20, Philips, Philips Medical Systems, Veenpluis, The Netherlands) with a flat panel detector: frontal and lateral planes (48 cm) with variable fields of view of 42-37-31-26-22-19-15 cm. The system is provided with the high-power X-ray tube and Spectra Beam filtration (Copper filters: 0.2, 0.5, and 1.0 mm CU) which reduces patient X-ray (radiographic) dose and provides great image quality. The angiography unit has three pulsed fluoroscopy modes, of 10, 30, and 60 P/s, of which 30 P/s is used most frequently. The system includes real-time relevant dose information.

Data were collected separately for frontal and lateral views but were added together and compared for analysis.

The following variables were taken into account for this study: KAP, AK and fluoroscopy exposure time. Also, PSD and ED were calculated, since they are not routinely measured. PSD is a good indicator of the potential for deterministic injury. The radiation dose parameter associated with the risk of stochastic effects is ED. KAP was used to estimate both ED and PSD in previous studies, although conversion factors normally entail a degree of uncertainty or error [11, 14, 19, 21–23]. PSD was calculated from a published dose conversion formula for interventional procedures as follows: PSD (mGy) = 249 + 5.2 x KAP ($Gy \cdot cm^2$) [21, 24]. We estimated ED from KAP using a dose conversion factor (DCC), where DCC= ED (mSv)/KAP ($Gy \cdot cm^2$) [21]. We calculated brain dose using ED and tissue weighing factor provided by ICRP-103 [25]. In this calculation, the distribution of probability was considered to be normal, but due to the somewhat skewed distribution of our data, a coverage factor of 3 was used.

The study data were analyzed using the SPSS version 21 statistical software (SPSS Inc, Chicago, IL) [26]. Descriptive statistics was performed. The significance of difference between values of examined variables by groups (diagnostic, therapeutic and combined procedures) was tested with the Kruskal-Wallis nonparametric analysis of variances, since data was not normally distributed. We performed *post hoc* test using the Mann Whitney test with the Bonferroni correction of critical value for significance of every test.

Results

From the angiographic database, totally 300 diagnostic and therapeutic INR procedures were identified. There were 224 cerebral angiographies, 55 therapeutic procedures (52 aneurism embolizations and 3 AVM embolizations) and 21 combined procedures. In total, there were 245 patients. Out of them, 55 patients [males (m)= 17; females (f) = 38, mean age = 49.35 ± 13.73 years] were exposed to radiation twice, 21 patients (m = 6; f = 15, mean age = 52.05 ± 13.23 years) were exposed to both diagnostic and therapeutic doses, while 169 patients (m = 77; f = 92, mean age = 51.62 ± 13.98 years) were exposed only to diagnostic radiation doses.

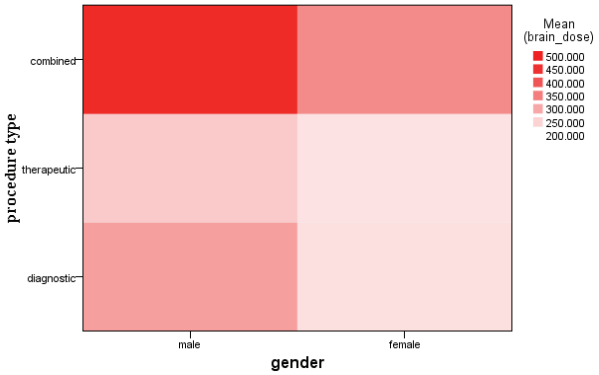

Fig. 1 – Heat map for mean (estimated) brain dose depending on patient' gender and procedure type.

We calculated total mean ± standard deviation and third quartiles for all dependent variables: KAP (93.95 ± 50.48 Gy·cm^2; 116.23 Gy·cm^2), AK (595.23 ± 382.07 Gy; 680.94 Gy); T (7.43 ± 7.37 min; 9.26 min); ED (13.62 ± 7.32 mSv; 16.85 mSv) and PSD (0.49 ± 0.26 Gy; 0.60 Gy). Estimated brain doses for diagnostic, therapeutic, combined and all procedures in total were: 254.62 ± 181.72 mGy, 227.84 ± 167.35 mGy, 341.12 ± 185.41 mGy and 272.4 ± 183.82 mGy, respectively. Figure 1 presents mean brain doses depending on the patients' gender and procedure type, using colors instead of numbers. Estimated brain doses for all three procedure types did not show normal distribution ($p = 0.001$), and frequency histogram is presented in Figure 2. Main statistical parameters for all three procedures types, as well as the Kruskal-Wallis test results are presented in Table 1.

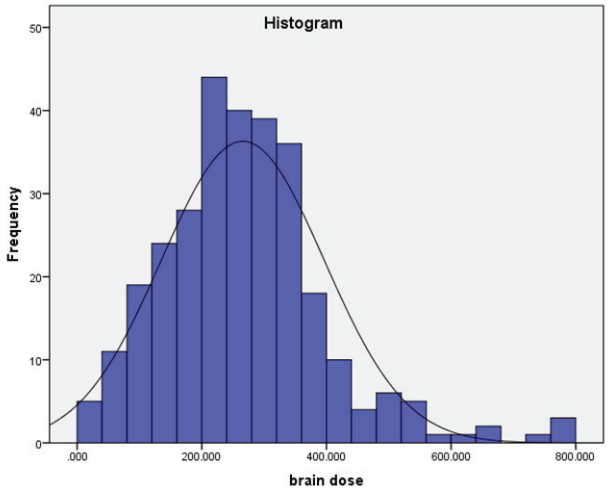

Fig. 2 – Frequency histogram for estimated brain dose.

Table 1

Mean, minimum and maximum values for KAP, AK, T, ED and PSD for all three procedures types

Parameters	Diagnostic procedure (n = 224)	Therapeutic procedures (n = 55)	Both diagnostic and therapeutic procedures (n = 21)	Kruskal-Wallis test
KAP (Gy·cm^2)				
median	87.802	78.567	117.626	Median = 86.514
minimum	2.710	11.685	29.673	$\chi^2 = 6.075$
maximum	342.301	263.005	322.655	$p = 0.048$
AK (Gy)				
median	495.019	642.631	860.280	Median = 524.685
minimum	8.586	35.170	135.188	$\chi^2 = 15.63$
maximum	1905.900	2486.620	2984.920	$p = 0.000$
T (min)				
median	3.690	11.670	12.880	Median = 4.8
minimum	0.53	2.380	2.820	$\chi^2 = 81.488$
maximum	25.070	42.870	43.230	$p = 0.000$
ED (mSv)				
median	12.731	11.392	17.056	Median = 12.544
minimum	0.393	1.694	4.303	$\chi^2 = 6.075$
maximum	49.634	38.136	46.785	$p = 0.048$
PSD (Gy)				
median	0.456	0.409	0.612	Median = 0.450
minimum	0.014	0.061	0.154	$\chi^2 = 6.075$
maximum	1.780	1.368	1.678	$p = 0.048$

KAP – kerma-area product; AK – air kerma; T – fluoroscopy time; ED – effective dose; PSD – peak skin dose.

The Kruskal-Wallis nonparametric analysis of variance showed that there was a significant difference between groups in term of dependent variables (KAP, AK, T, ED and PSD) and procedure type. *Post hoc* analysis determined by the Bonferroni correction of critical values was significant for each test: KAP and procedure type ($p = 0.016$), AK and procedure type ($p = 0.000$), T and procedure type ($p = 0.000$), ED and procedure type ($p = 0.016$), PSD and procedure type ($p = 0.016$).

Discussion

Our study presented radiation exposure of patients during INR procedures by analyzing measured values by angiographic units (Kap, AK and T). We used KAP to assess and estimate ED and PSD, since previous studies have shown that it is the most effective way for determination of stochastic and deterministic effects of radiation during INR procedures.

The ICRP 103 states that ED should not be used for individual dose estimates nor for retrospective studies of individual radiation risk [25]. There are numerous formulas and DCCs for conversion of KAP to ED [11, 14, 24]. Choosing the right one is not easy, especially for neuroradiology procedures, because of limited number of published data and different angiographic units used. Also, comparison of ED is possible only with optimum DCC. Our study estimated that total mean absorbed dose by the brain was 272.4 mGy while brain dose during therapeutic procedures was 227.84 mGy. Previous study [11] presented that in 34% of patients, this dose was higher than 500 mGy, which is a threshold set by the ICRP [25]. The authors of that study used dose conversion factor different from the one we used and no clear information was given about the conversion formula, although the same angiographic unit was used as in our study. The study [21] that used the same DCC as us, due to accords with tube geometry and the beam quality, showed that their mean ED was 12.4 mSv which is much more than previously mentioned study, and in accordance with our mean therapeutic ED (11.392 mSv). In that study total mean EDs during interventional vascular procedures were: 6.2 mSv, 12.7 mSv, 27 mSv and 11.7 mSv [21].

Our estimated total mean PSD was 0.489 Gy, while maximum and minimum values were: 1.78 Gy and 0.014 Gy. PSD allows us to determine the possibility for a patient to receive a radiation skin injury [10, 23]. Suggested threshold is 2 Gy [11, 21, 23]. Our study showed results below the threshold. Only 3 patients had PSD higher than 1.5 Gy and none of the skin injuries, like erythema were reported. Other studies showed that their estimated total mean PSDs were 0.44 Gy and 1.01 Gy [21, 23]. Still, estimating PSD from KAP is problematic because during interventional procedures X-ray tube is moved around the patient, thus irradiating different areas of the skin. Also, there are different conversion formulas used for conversion of KAP to PSD. Even though, our estimation of PSD showed that suggested threshold was not reached, which complied with absence of skin injuries in our patients.

Our study showed that median KAP and T during intracranial aneurism and AVM embolizations were 78.567 Gy·cm^2 and 11.670 min, respectively. A study that had included patients with aortic aneurism showed that their KAP and T were 106.765 Gy·cm^2 and 17.32 min, respectively [27]. Average KAP in one of INR studies was 230 Gy·cm^2 [11], while our total average KAP was 93.95 Gy·cm^2.

Differences between our results and those in previously published studies may exist due to different methods in calculation of ED. This is the main limitation of our study. Nevertheless, we consider that ED and brain dose can give us some sense of direction, which might be better than having none.

Conclusion

INR procedures show significant variability in radiation doses due to a patient constitution, radiologist expertise and equipment factors. Knowing a radiation dose during INR procedures can have a great benefit for patients and also for medical and paramedical staff. There are cases where medical indication can justify the dose, but in other cases it is important to do anything we know to reduce the risk of deterministic and stochastic effects of ionizing radiation.

In our study statistically significant difference was noted between procedures (diagnostic, therapeutic, and combined), although threshold values were never reached. A mean total absorbed dose by the brain was far less than the threshold value, which was also never reached in our study, although previous studies suggested that excessive amount of radiation (> 500 mGy) occurs in about a third of patients. PSD over 1.5 Gy, which was close to the threshold value, was present in a few cases, however, not causing any skin injuries.

Our study suggests that INR procedures are safe in terms of radiation exposure even when a patient undergoes combined interventions.

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