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RADIATION EXPOSURE DURING NEUROINTERVENTIONAL PROCEDURES IN MODERN ANGIOGRAPHIC SYSTEMS: A SINGLE CENTER EXPERIENCE

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Abstract

Background/Aim. Interventional neuroradiology procedures expose patients to ionizing radiation. The aim of this study was to assess the 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 the 1st 2014 to December the 1st 2016. The following variables were considered for this study: kerma-area product, air kerma and fluoroscopy exposure time; peak skin dose and effective dose were calculated from the kerma-area product. Results. Median kerma-area product was (87.802 Gy cm$^{-2}$, 78.567 Gy cm$^{-2}$, 117.626 Gy cm$^{-2}$), effective dose (12.731 mSv, 11.392 mSv, 17.056 mSv) peak skin dose (0.456 Gy, 0.409 Gy, 0.612 Gy) and estimated brain dose (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 the patients and medical and paramedical stuff in terms of prevention of possible deterministic and stochastic effects of the radiation.

Key words: intervention, neuroradiology, radiation, dose, exposure.

Apstrakt

Uvod/Cilj. U toku interventnih neuroradioloških procedura pacijenti su izloženi jonizujućem zračenju. Cilj ove studije je da proceni doze jonizujućeg zračenja koje pacijent primiti tokom interventnih neuroradioloških procedura i da utvrdi granice izlaganja do kojih pacijenti nemaju negativne efekte i posledice uticaja jonizujućeg zračenja. Metode. Studijom su obuhvaćeni svi pacijenti kojima su urađene dijagnostičke i/liti terapijske procedure na Odseku Interventne Neuroradiologije u Kliničkom Centru Kragujevac, Srbija, u periodu od 1. decembra 2014. godine do 1. decembra 2016. godine. Sledeće vrednosti su beležene: „kerma-area product“; „air kerma“; vreme izloženosti jonizujućem zračenju; maksimalna kožna doza i efektivna doza. Rezultati. Srednja vrednost „kerma-area product“ bila je 87.802 Gy cm$^{-2}$, 78.567 Gy cm$^{-2}$, 117.626 Gy cm$^{-2}$; efektivne doze 12.731 mSv, 11.392 mSv, 17.056 mSv; maksimale 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. Zaključak. Interventne neuroradiološke procedure pokazuju izrazitu varijabilnost u emitovanoj i primljenoj dozi zračenja, u zavisnosti od faktora kao što su konstitucija pacijenata, oprema, kao i iskustvo radiologa. Poznavajući veličine ovih doza zračenja u različitim uslovima, kao i uz upotrebu mera prevencije mogućih determinističkih i stohastičkih efekata radijacije, moguće je znatno smanjiti primljene doze zračenja kako za pacijenta, tako i za osoblje.

Ključne reči: interventne procedure, neuroradiologija, jonizujuće zračenje.
Introduction

Interventional neuroradiology (INR) procedures are guided by imaging techniques and both are performed as diagnostic and/or therapeutic (1). Its use shows constant increase, because of the great benefit they have for the patients (2). However, INR procedures expose patients to ionizing radiation (3). The radiation risk is presented as deterministic effect, which happens after exceeding the threshold, and stochastic effect, which doesn’t have a threshold (4,5). Despite the technological improvements, there are other risk factors such as procedure complicatedness, longer time of fluoroscopy and high dose rates, which contribute to the increase of the skin injuries and to the occurrence of stochastic effects such as carcinoma (3,4,5,6). 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 (8,9,10).

The International Commission on Radiologic Protection (ICRP) proposed that threshold for dose absorbed by patients’ brain should be 0.5 Gy (11,12). It was also suggested that such high doses could be avoided by real-time observation of doses by the INR specialists, following proper consultation to their patients and optimization of the 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). Kerma-area product does not supply us with direct radiation risk effect, but can be used to create dose reference level, together with air kerma and fluoroscopy time (14,16). Dose reference levels are usually set as the 75th percentile and are defined as degree of radiation exposure which shouldn’t 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, average brain dose was 500 mGy and third quartile was 856 mGy, while for cerebral angiography, the average brain dose was 100 mGy (11). This study didn’t show the exact formula or conversion factor from KAP to ED, but cite the website that was used for calculation (11,18).

There is little information in the literature regarding patient exposure to the radiation during interventional neuroradiology procedures. The most of the studies that are already published were conducted on cardiac and other vascular procedures, or show variations in number of patients and dose calculation (8,9,10,14,17,19,20). To our knowledge, there is limited data on radiation indicators during INR procedures and especially on brain dose. The aim of this study was to assess the doses received by patients during interventional neuroradiology 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 the 1st 2014 to December the 1st 2016. The study was approved by our Institutional Ethics Committee. Data that was used for the study were collected from the angiographic database.
We included all patients who underwent diagnostic procedures (cerebral angiographies) and therapeutic interventional neuroradiology procedures: aneurism embolization and embolization of arteriovenous malformation (AVM). Follow-up diagnostic procedures, after therapeutic ones, were excluded. All procedures were performed by a team of two experienced interventional neuroradiologists. Both of radiologist had performed over 1000 aneurysm and AVM embolizations and have 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 was 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 dose and provides great image quality. The angiography unit had three pulsed fluoroscopy modes, of 10, 30, and 60 P/s, of which 30 P/s was used most frequently. The system included 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: kerma-area product, air kerma and fluoroscopy exposure time. Also, peak skin dose and effective dose were calculated, since they are not routinely measured. Peak skin dose provides a good indicator of the potential for deterministic injury. The radiation dose parameter associated with the risk of stochastic effects is effective dose. KAP has been used to estimate both effective dose and peak skin dose in previous studies, although the conversion factors normally entail a degree of uncertainty or error (11,14,19,21,22,23). PSD was calculated from a published dose conversion formula for interventional procedures as follows: PSD (mGy) = 249 + 5.2 x KAP (Gy cm^-2) (21,24). We estimated effective dose from KAP using a dose conversion factor (DCC), where DCC = ED (mSv) / KAP (Gy cm^-2) (21). We calculated brain dose using the effective dose 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 Kruskal-Wallis nonparametric analysis of variances, since data wasn’t normally distributed. We performed post hoc test using Mann Whitney test with Bonferroni correction of critical value for significance of every test.

Results

From the angiographic database, in total, 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 (m=17, f=38, mean age=49.35±13.73) were exposed to radiation twice, 21 patients (m=6, f=15, mean age=52.05±13.23) were exposed to both diagnostic and therapeutic dose, while 169 patients (m=77, f=92, mean age=51.62±13.98) were exposed only to diagnostic radiation dose.

We have 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 dose depending on the patient gender and procedure type, using colors instead of numbers. Estimated brain dose for all three procedure types didn’t 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 Kruskal-Wallis test results are presented in Table 1.

Table 1. Mean, minimum and maximum values for KAP, AK, T, ED and PSD for all three procedures types, and Kruskal-Wallis test results

<table>
<thead>
<tr>
<th></th>
<th>Diagnostic procedure (n=224)</th>
<th>Therapeutic procedures (n=55)</th>
<th>Both diagnostic and therapeutic procedures (n=21)</th>
<th>Kruskal-Wallis test</th>
</tr>
</thead>
<tbody>
<tr>
<td>KAP (Gy∙cm²):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• median</td>
<td>87.802</td>
<td>78.567</td>
<td>117.626</td>
<td>Median=86.514</td>
</tr>
<tr>
<td>• minimum</td>
<td>2.710</td>
<td>11.685</td>
<td>29.673</td>
<td>p=0.048</td>
</tr>
<tr>
<td>• maximum</td>
<td>342.301</td>
<td>263.005</td>
<td>322.655</td>
<td>Chi-Square=6.075</td>
</tr>
<tr>
<td>AK (Gy):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• median</td>
<td>495.019</td>
<td>642.631</td>
<td>860.280</td>
<td>Median=524.685</td>
</tr>
<tr>
<td>• minimum</td>
<td>8.586</td>
<td>35.170</td>
<td>135.188</td>
<td>p=0.000</td>
</tr>
<tr>
<td>• maximum</td>
<td>1905.900</td>
<td>2486.620</td>
<td>2984.920</td>
<td>Chi-Square=15.63</td>
</tr>
<tr>
<td>T (min):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• median</td>
<td>3.690</td>
<td>11.670</td>
<td>12.880</td>
<td>Median= 4.8</td>
</tr>
<tr>
<td>• minimum</td>
<td>0.53</td>
<td>2.380</td>
<td>2.820</td>
<td>p=0.000</td>
</tr>
<tr>
<td>• maximum</td>
<td>25.070</td>
<td>42.870</td>
<td>43.230</td>
<td>Chi-Square=81.488</td>
</tr>
<tr>
<td>ED (mSv):</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• median</td>
<td>12.731</td>
<td>11.392</td>
<td>17.056</td>
<td>Median= 12.544</td>
</tr>
<tr>
<td>• minimum</td>
<td>0.393</td>
<td>1.694</td>
<td>4.303</td>
<td>p=0.048</td>
</tr>
<tr>
<td>• maximum</td>
<td>49.634</td>
<td>38.136</td>
<td>46.785</td>
<td>Chi-Square=6.075</td>
</tr>
<tr>
<td>PSD (Gy) :</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• median</td>
<td>0.456</td>
<td></td>
<td></td>
<td>Median= 0.450</td>
</tr>
<tr>
<td>• minimum</td>
<td>0.014</td>
<td></td>
<td></td>
<td>p=0.048</td>
</tr>
<tr>
<td>• maximum</td>
<td>1.780</td>
<td></td>
<td></td>
<td>Chi-Square=6.075</td>
</tr>
</tbody>
</table>

KAP= kerma-area product, AK= air kerma, T= fluoroscopy time, ED= effective dose, PSD= peak skin dose

The Kruskal-Wallis nonparametric analysis of variances has shown that there is a significant difference between groups in terms of dependent variables (dose-area product, air-kerma, fluoroscopy time, effective dose and peak skin dose) and procedure type. Post hoc analysis determined Bonferroni correction of critical value which was significant for each test: KAP and procedure type (0.016), AK and procedure type (0.000), T and procedure type (0.000), ED and procedure type (0.016), PSD and procedure type (0.016).

Discussion

Our study presented radiation exposure of patients during interventional neuroradiology procedures by analyzing measured values by the angiographic unit (kerma-
area product, air kerma and fluoroscopy time). We used KAP to assess and estimate effective dose and peak skin dose, since previous studies have shown that it is the most effective way for determent of stochastic and deterministic effect of the radiation during INR procedures.

ICRP 103 states that the effective dose 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 isn’t easy, especially for neuroradiology procedures, because of the limited number of published data and different angiographic unit 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 the therapeutic procedure was 227.84 mGy. Previous study presented that in 34% of patients, this dose was higher than 500 mGy, which is a threshold set by ICRP (11,25). These authors used different dose conversion factor than us and didn’t give clear information about the conversion formula, although they used the same angiographic unit as us (11). The study that used same DCC as we have chosen, due to the accords with tube geometry and the beam quality, showed that their mean ED was 12.4 mSv which is much more in accordance with our mean therapeutic ED (11.392 mSv) than previously mentioned study (21). Other studies presented that total mean ED during their interventional vascular procedures was: 6.2 mSv, 12.7 mSv, 27 mSv and 11.7 mSv (21).

Our estimated total mean peak skin dose 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 show 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 PSD was 0.44 Gy, 1.01 Gy (21,23). Still, estimating PSD from KAP is problematic because during interventional procedures the X-ray tube is moved around the patient, thus irradiating different areas of skin. Also, there are different conversion formulas used for conversion of KAP to PSD. Even though, our estimation of peak skin dose showed that suggested threshold was not reached, which complies with absence of skin injuries in our patients.

Our study showed that median KAP and fluoroscopy time during intracranial aneurism and AVM embolization were 78.567 Gy-cm² and 11.670 min. Study that was done on patients with aortic aneurism showed that their KAP and T were 106.765 Gy-cm² and 17.32 min (27). Average kerma-area product in one of the interventional neuroradiology study was 230 Gy-cm², while our total average KAP was 93.95 Gy-cm² (11).

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

Conclusion

Interventional neuroradiology procedures show significant variability in radiation doses, due to patient constitution, radiologist expertise and equipment factors. Knowing the radiation dose during interventional neuroradiology procedures can have a great benefit for the 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 in our power to reduce the risk of deterministic and stochastic effects of the radiation.

In our study statistically significant difference was noted between the procedures (diagnostic, therapeutic, and combined), although the threshold values were never reached in our study. The 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. Peak skin dose over 1.5 Gy, which was close to the threshold value, was present in a few cases, however, not causing any skin injury.

Our study suggests that the interventional neuroradiological procedures are safe in terms of radiation exposure even when the patient undergoes combined interventions.

Acknowledgement

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REFERENCES


Fig. 1 – Heat map for mean(estimated) brain dose depending on the patient gender and procedure type.
Fig. 2 – Frequency histogram for estimated brain dose.