*Tomasz Roman[1], Maciej Szajner[1], Klaudia Karska[1], Justyna Markowicz-Roman[2], Katarzyna Hać[1], Ewa Kramarz[1], Łukasz Światłowski[1], Małgorzata Szczerbo-Trojanowska[1]

Radiation exposure in interventional neuroradiology

Narażenie na promieniowanie rentgenowskie w neuroradiologii interwencyjnej

[1]Department of Interventional Radiology and Neuroradiology, Medical University in Lublin
Head of Department: Professor Małgorzata Szczerbo-Trojanowska, MD, PhD
[2]Department of Clinical Immunology, Medical University in Lublin
Head of Department: Professor Jacek Roliński, MD, PhD

Keywords
neuroradiology, embolization, radiation

Słowa kluczowe
neuroradiologia, embolizacja, promieniowanie rentgenowskie

Conflict of interest
Konflikt interesów
None
Brak konfliktu interesów

Address/adres:
*Tomasz Roman
Department of Interventional Radiology and Neuroradiology
Medical University in Lublin
ul. K. Jaczewskiego 8, 20-954 Lublin
tel. +48 (81) 724-41-54
fax +48 (81) 724-48-00
tomek.gov@gmail.com

S u m m a r y

Constant development of interventional neuroradiology procedures increases number and sometimes length of vascular interventions. There are several factors that have impact on total radiation dose during neuroembolization. Reaction of human body to radiation exposure may be different. In general, it depends on severity of exposure and time in which it occurs. In this review, only dose measurements applicable for C-arm devices will be taken for consideration. There are several methods for x-ray use assessment during interventional neuroradiology procedures. This is important for operating physician to understand their definitions and practical implications for most appropriate dose control during procedures. Most important reasons for recording of patient dose are patients safety and dose optimization as a feedback to the operator. The procedures with potentially high dose risk may be enlisted and performed with greater awareness. Increasing awareness of epidemiological data on radiation-induced diseases should improve dose management.

S t r e s z c z e n i e

Ciągły rozwój neuroradiologii interwencyjnej wpływa na wzrost liczby procedur, a także w niektórych przypadkach na wydłużenie czasu zabiegów. Istnieje szereg czynników mogących wpływać na całkowite narażenie na promieniowanie rentgenowskie podczas neuroembolizacji. Obserwuje się różne skutki uboczne, pojawiające się w zależności od dawki oraz czasu narażenia. W tym opracowaniu przeglądowym pod uwagę będą brane sposoby pomiaru dawki właściwe dla ramienia C. Zrozumienie ich rodzajów, definicji oraz zastosowań praktycznych jest bardzo istotne dla operatora przy ocenie i kontroli narażenia pacjenta na promieniowanie rentgenowskie. Ważne jest także dokumentowanie dawek, nie tylko w celu świadomego zwiększania bezpieczeństwa pacjenta, ale także jako informacji zwrotnej dla lekarza. Ocena trudności zabiegu powinna zawierać także szacunkową ocenę pod kątem możliwego ryzyka związanego z promieniowaniem. Operator powinien mieć także podstawową wiedzę w zakresie epidemiologii chorób związanych z narażeniem na promieniowanie rentgenowskie.

INTRODUCTION

Interventional neuroradiology is fast developing branch of medicine providing various endovascular techniques for treatment of brain vascular diseases. Both materials and radiological equipment are constantly improving. However, the risks connected with exposure to radiation are still important limitation of such approach.

There are several factors that have impact on total radiation dose during neuroembolization. Those may be related directly to patient or to operating techniques and equipment. They are summarized in table 1. Increasing awareness of side effects of radiation and undertaking efforts to optimize x-ray use is important part of radiologists practice.

EFFECTS OF RADIATION

Reaction of human body to radiation exposure may be different. In general, it depends on severity of exposure and time in which it occurs. For academic purposes, these health consequences may be divided into stochastic and deterministic effects. The severity

Tab. 1. Risk factors concerning radiation of interventional neuroradiology patient

Radiation risks related to patient	Radiation risks related to operating techniques and equipment
Age	Position of a table
Sex	Collimation
Weight	Frames per second
Prior history of radiation	Image quality presets
Specific area – brain, covered with skull	Area of imaging
	Biplane vs monoplane, including overlying of fields
	Learning curve

of stochastic effects does not depend on total dose absorbed, but the chance of incidence increases along with amount of radiation. The key examples of stochastic effects of radiation are cancers, in that case as radiation-induced. Deterministic effects, in the other hand, are correlated positively with received dose. The threshold dose can be defined for them, keeping in mind that it can be variant depending on particular cases. After exceeding a individual threshold level, damage appears accordingly to increasing dose. Most common deterministic effects to observe in neuroradiology suite are skin injury, hair loss and erythema.

DOSE MEASUREMENT

In this review, only dose measurements applicable for C-arm devices will be taken for consideration. There are several methods for x-ray use assessment during interventional neuroradiology procedures. This is important for operating physician to understand their definitions and practical implications for most appropriate dose control during procedures.

The fluoroscopy time, as well as total images count may be related to patient dose, but they can vary between different procedures with the same effective dose. Information about fluoroscopic dose rate and the dose per image must be also provided. The fluoroscopy time and fluoroscopic images count are considered to be least relevant for dose monitoring.

Kerma-area product (PKA) is another commonly available indicator for most of the angiographic suites. It is defined as “integral of air kerma across the entire x-ray beam emitted from the x-ray tube” (1). PKA is measured in Gy·cm^2. The scatter is usually not included in the given value, which is usually measured by fluoroscope. This value represents total radiation energy entering the patient. It is approved by International Commission on Radiation Units and Measurements (ICRU) commission as indicator of future probability of stochastic effects to the patient. There are observations proving that PKA correlates also with staff dose. However, this parameter is not considered to be good indicator of deterministic effects.

Reference air kerma (Ka,r), also know an reference point air kerma (called cumulative dose or cumulative air kerma) represents air kerma that is being concentrated at the interventional reference point. This radiation measurement does not include backscatter from the patient. The value is given in Grays (Gy) and it can be measured by most fluoroscopic units. The interventional reference point (also known as patient entrance reference point) for C-arm is located 15 cm from its isocenter towards the x-ray tube. The Ka,r is considered to be an estimation value for skin dose, however some observations suggests that it may overestimate the risks (2). Important limitation there is that the interventional reference point may be located at different distance from the patient’s skin, depending on the table height, beam angle, as well as dimensions of current individual. This is main source of estimation while using Ka,r as skin dose measurement.

Effective dose is amount of energy delivered to certain organs and tissues and therefore is referring to local effects. The formula includes sensitivity factor for that tissue. The calculation of effective dose is based on certain body models, gained from different observations. That means certain amount of estimation. Still, effective dose remains to be most widely used indicator of radiation risk to individual members of population. The effective dose is expressed in sieverts (Sv).

THRESHOLDS

There are different threshold definitions being currently in use. The common idea is to mark highest safe radiation level according to certain procedure or examination. The American National Council on Radiation Protection & Measurements (NCRP) proposed that potentially risky procedure exceeds Ka,r over 3 Gy or PKA over 300 $Gycm^2$ (3). The Society of Interventional Radiology (SIR) named certain procedures, such as embolization procedures in general, transjugular intrahepatic portosystemic shunt (TIPS) procedures and angioplasty and stent placement in abdomen or pelvis (4). The threshold proposed by International Commission on Radiological Protection (IRCP) is proposed at the level, when a probability of radiation injury is 1%. For the brain, safe point was set at 500 mGy (5). Observation of population-based models also may deliver useful threshold values. For example, observations by Shimizu et al. on Hiroshima and Nagasaki atomic bomb survivors, made between 1950 and 2003, report 9% increase of risk for stroke death per Grey for brain doses > 0.5 Gy (6). Data provided by IRCP indicate, that radiation at level of 1-2 Gy may be harmful for developing brain of children, causing them cognitive and behavioral defects. The infants under 18 months of age may suffer such effects even after exceeding 0.1 Gy (5).

The important issue with threshold setting is that some of the deterministic effects of radiation may have late manifestation, which can vary between individuals. That should make medical staff extra cautious, especially with young patients, having long-term life expectancy.

DOSE RECORDING

Most important reasons for recording of patient dose are patients safety and dose optimization as a feedback to the operator. The procedures with potentially high dose risk may be enlisted and performed with greater awareness. The SIR practice guidelines recommend that all radiation dose data should be gathered in final report and should be archived along with images gained (7). European Union also announced directive stating that “information relating to patient exposure forms part of the report of the medical radiological procedure” (8). The legislation covering this area may be different in many countries. Most of currently available produced angiographic units is able to create automatic report on radiation use and archive it automatically.

There local or institucional observations may be also made to acknowledge radiation exposure and revisit working protocols in order to optimize it.

REPORTS ON PATIENT RADIATION EXPOSURE IN NEURORADIOLOGY

There are some publications reporting radiation exposure of patients undergoing endovascular treatment of cerebrovascular diseases. We describe some of them for descriptive purposes.

Miller et al. published in 2003 results of first part of RAD-IR study, containing overall measurements of fluoroscopy use parameters, including neurointerventional procedures. These are summarized in table 2 (2). This is a prospective observational study conducted to determine patient radiation doses for interventional radiology and neuroradiology procedures, including over 2000 cases.

Sanchez et al. calculated doses to the brain during cerebral angiography and embolization using PCXMC 2.0 Rotation software (9). Mean dose to the brain during angiography (61 procedures) was 0.1 Gy, ranging between 0.026 and 0.568 Gy. Mean dose for cerebral embolization (38 procedures) was 0.5 Gy, with range 0.0155-1.678 Gy. The mean value for embolization was at the highest save level recommended by IRCP. The median value was 0.397 Gy, which means that most of the procedures reached result below this threshold.

Thierry-Chef et al. assessed brain doses in pediatric population (10). The study group consisted of pediatric subpopulation of RAD-IR study – 49 cases that underwent neuroembolization. Calculation of brain dose was based on an age-dependent mathematical model of the brain developed by the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine in order to take under consideration the growth of the organ. The Monte Carlo-based software PCXMC was also used for analysis of dose to the brain. This article provides detailed informations of PKA, estimated doses to the brain and skin dose analysis according to age of patients.

MULTISTAGE TREATMENT AND RADIATION RISK

Despite of constantly improving neurointerventional techniques, some cases require multistage approach. This may produce of events defined as a radiation overdose sentinel events (FSE) (11). These events occur as radiation-induced skin injuries. Interventional neuroradiology procedures are considered to be among of the highest risk-related procedures (10). The threshold for these events is set at 15 Gy of cumulative peak skin dose to a single field, accumulated in period of time between 6 months and 1 year. The monitoring of such events is important not only from clinical point of view, it may also inform about necessity of reevaluating procedure protocols. Operating physician cannot monitor peak skin dose in course of vascular intervention. As it was pointed before, the Ka,r is most useful for monitoring skin dose. Dose management, however, requires team effort and should not be considered only as responsibility of radiologist. All physicians participating in treatment of a case with potential radiation-induced skin injury should be notified and the radiation history should be available in medical history. Skin reactions presenting after the procedure should be treated as radiation induced until they are diagnosed otherwise. The report of NRCP commission advocates, that after exceeding the threshold for FSE, clinical observation should be conducted for 1 year (12). Frequent exceeding the FSE threshold should be answered with review of fluoroscopy use protocols. The dose mode, pulse rate, magnification use, collimation and table positioning should be taken into consideration.

Tab. 2. Summary of fluoroscopy use parameters in neuroradiology – subgroup of Rad-IR study (2)

Values	Arteriovenous malformation (n = 177)	Aneurysm (n = 149)	Tumor (56)	Stroke (9)
PKA (mean, Gycm^2)	3397.6	2826.9	3577.6	1982.4
PKA (range, Gycm^2)	3980-13511.1	678.8-8251.5	458.7-9559	792.4-4617.1
Ka,r (mean, Gy)	3.791	3.767	3.865	4.935
Ka,r (range, Gy)	43-13410	1.284-9.809	0.598-10.907	2.380-7.504
Fluoroscopy time (mean, min)	92.5	75.0	106.0	42.9
Fluoroscopy time (range, min)	2.6-313.7	15.2-401.3	16.2-276.5	19.1-89.5
Number of images (mean)	1037	1070	1138	563
Number of images (range)	71-2654	292-2440	364-2612	290-1092

CONCLUSIONS

Radiation exposure management during interventional neuroradiology is important part of medical practice. Understanding ways of dose measurement and monitoring can help avoid or limit side effects. Awareness of epidemiological data on radiation-induced diseases should improve dose management.

BIBLIOGRAPHY

1. Stecker MS, Balter S, Towbin RB et al.: SIR Safety and Health Committee; CIRSE Standards of Practice Committee. Guidelines for patient radiation dose management. J Vasc Interv Radiol 2009; 20(7 Suppl): S263-73.
2. Miller DL, Balter S, Cole PE et al.: Radiation doses in interventional radiology procedures: the RAD-IR study part II. Skin dose. J Vasc Interv Radiol 2003; 14: 977-990.
3. National Council on Radiation Protection and Measurements. Radiation dose management for fluoroscopically guided interventional medical procedures. Report No. 168. Bethesda, MD: NCRP, 2011.
4. Miller DL, Balter S, Wagner LK et al.: Quality improvement guidelines for recording patient radiation dose in the medical record. J Vasc Interv Radiol 2004; 15: 423-429.
5. ICRP Statement on Tissue Reactions/Early and Late Effects of Radiation in Normal Tissues and Organs-Threshold Doses for Tissue Reactions in a Radiation Protection Context. ICRP Publication 118. Ann. ICRP 41(1/2) 2012.
6. Shimizu Y, Kodama K, Nishi N et al.: Radiation exposure and circulatory disease risk: Hiroshima and Nagasaki atomic bomb survivor data, 1950-2003. BMJ 2010; 14: 340:b5349.
7. American College of Radiology. ACR-SIR Practice Guideline for the Reporting and Archiving of Interventional Radiology Procedures. Reston, VA: American College of Radiology, 2009.
8. European Commission. COUNCIL DIRECTIVE 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. Available at http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=OJ:L:2014:013:TOC Accessed February 27.09.2014.
9. Sanchez RM, Vano E, Fernández JM et al.: Brain radiation doses to patients in an interventional neuroradiology laboratory. AJNR Am J Neuroradiol 2014; 35(7): 1276-1280.
10. Thierry-Chef I, Simon SL, Land CE et al.: Radiation dose to the brain and subsequent risk of developing brain tumors in pediatric patients undergoing interventional neuroradiology procedures. Radiat Res 2008; 170: 553-565.
11. Vance AZ, Weinberg BD, Arbique GM et al.: Fluoroscopic sentinel events in neuroendovascular procedures: how to screen, prevent, and address occurrence. AJNR Am J Neuroradiol 2013; 34(8): 1513-1515.
12. National Council on Radiation Protection and Measurements. Radiation Dose Management for Fluoroscopically-Guided Interventional Medical Procedures. Bethesda, Maryland: National Council on Radiation Protection and Measurements; 2010. NCRP Report No. 168.

received/otrzymano: 02.03.2017
accepted/zaakceptowano: 24.03.2017