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Review

Patient exposure to ionising radiation due to nuclear medicine cardiac procedures

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Abstract

Nuclear cardiology procedures are among the most extensively performed radionuclide studies. Procedures for the assessment of myocardial perfusion, contractile function and metabolism have gained a prominent position in clinical practice. Health risk to patients from radiopharmaceuticals results only from exposure to ionizing radiation. Nuclear medicine diagnostic procedures, including the cardiological ones, are accompanied by a very small risk of radiation induced malignant tumours. Death risk from stress and rest perfusion of myocardium (effective dose of about10 mSv) could be estimated as lower than 0.1 per mille.
Key words: nuclear cardiology, radiation risk, effective dose, radiation induced tumour

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Introduction

In Poland — as in other European countries — nuclear cardiology procedures belong to most extensively performed scintigraphic studies. In the United States where nuclear cardiology is particularly well developed, those procedures form more than 50% of all nuclear medicine procedures. A collective dose from this source accounts for ~85 percent of the total dose to patients undergoing nuclear medicine diagnostics [1].

The contemporary nuclear medicine applies methods for the assessment of myocardial perfusion, contractile function, metabolism, viability, innervation, and also detection of regions of necrosis and apoptosis in myocardium. Procedures for assessment of perfusion, contractile function and metabolism gained a prominent position in clinical practice. The most frequent procedure among those listed above is assessment of myocardial perfusion.

A gamma radiation is an information carrier in radionuclide diagnostics, the quanta of this radiation are emitted by short lived radionuclides introduced into the organism by means of injected radiopharmaceuticals. The role of a radiation emitter can be played by radioactive element or by a compound containing a radioactive atom in its structure. After intravenous injection radiopharmaceuticals are taken up, cumulated and eliminated from a myocardium or travel through heart cavities. Kinetics of these processes reflect various physiological functions and may reflect and localise abnormalities resulting from diseases of the heart and circulatory system.

These processes can by registered by means of external measurements using scintillation cameras, thanks to high penetration of gamma rays through patient body. The imaging instruments enable both planar as well as tomographic visualization of myocardium by SPECT (single photon emission tomography) modality and by PET (positron emission tomography) techniques. (Additionally, X-rays produced by hybrid SPECT/CT and PET/CT instruments provide three-dimensional tissue density maps. Basing on transmission data it is possible to correct for the gamma ray absorption by tissues surrounding the heart. This procedure provides more accurate data on distribution of a radiopharmaceutical in myocardium [2]. Due to the fact that CT scanners mounted additionally on hybrid instruments work during cardiac studies in a low dose mode, use of CT rises a radiation to a patient only slightly (more precise values will be presented later).

The most important advances of nuclear cardiology are:

— usually unique character of diagnostic information, normally very difficult to derive or just impossible to obtain by other methods (like CT, MRI or ultrasonography). This applies to

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regional blood perfusion at the cardiomyocyte level and myocardial metabolism and provides a composite insight into blood perfusion and contractility of myocardium;
— easy obtaining of required scintigraphic images. In contrast to echocardiography the anatomic conditions only slightly affect quality and reliability of results;
— semiquantitative or quantitative character of diagnostic informations;
— good reproducibility of results. This is due to limitation of subjective factors in the process of their acquisition and processing, usually semi- or fully automatic;
— noninvasiveness — radiopharmaceuticals are supplied to patients by intravenous injections. The mass administered is extremely small (usually in the order of micrograms in a few mililiters of physiological saline), therefore it does not influence a patient body in a noticeable way.

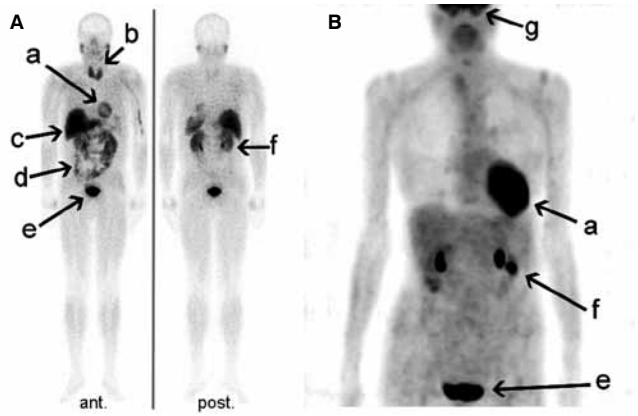

Figure 1. Biodistribution of radiopharmaceuticals. **A.** ^{99m}Tc-MIBI (myocardial perfusion study — SPECT); **B.** ^{18}F-fluorodeoxyglucose (myocardial viability study — PET); a — heart; b — thyroid; c — liver; d — intestines; e — urinary bladder; f —kidneys; g — brain

Radiation doses, health risk

A health risk to patients from radiopharmaceuticals results only from exposure to ionizing radiation — gamma rays and positrons — when PET technique is used, which in effect of annihilations with electrons also produce some gamma rays.

The radiation risk depends on doses absorbed by patient organs. The absorbed dose of radiation has been defined as a ratio of energy deposited and a mass of an absorbing tissue. The unit of absorbed radiation is 1 Gray (Gy) which equals 1 Joule of energy per 1 kg of tissue. The magnitude of such a dose is usually classified as large when it exceeds 1 Gy; low doses are those below 0,1 Gy (100 mGy) [3]. Intermediate doses are those between the two classes defined above.

An effective dose has been defined by the ICRP (International Committee on Radiological Protection) [4] for an assessment of a risk to whole human body. This kind of dose takes into account different sensitivity of organs to radiation as well as different relative biological effectiveness of various kinds of ionizing radiation. However, in case of nuclear medicine studies relative biological effectiveness of radiations used for diagnostic purposes (gamma and beta plus) is equal to one. Therefore the effective dose is a sum of the products of absorbed doses in organs and tissues and their sensitivity factors. Radiopharmaceuticals cause differentiated exposition of organs due to inhomogeneous distribution of activity in a human body. Radiopharmaceuticals used in nuclear cardiology also show affinity for another tissues and organs, like brain, thyroid, skeletal muscles, liver. Moreover, they are transported with body fluids and are secreted in gastro-intestinal and urinary tracts (Figure 1). This is why calculation of an effective dose resulting from administration of a radiopharmaceutical must take into account its distribution and kinetics in the whole body. The unit of the effective dose is named sievert [Sv]. In practice, for the assessment of the risk to patients smaller dose units are used (milisievert — 0.001 Sv). Effective doses to humans from gamma and beta plus radiations emitted by radiopharmaceuticals applied in diagnostic cardiac procedures and, for comparison, also doses from X ray studies in several radiological procedures applied in cardiology are presented in Tables 1 and 2. As was mentioned earlier, additional use of low dose CT during cardiac SPECT of PET studies rises a radiation to a patient only slightly, by 1–1.5 mSv [5, 6]. It can be seen that both imaging modalities (nuclear medicine and radiological) are sources of similar or slightly lower effective doses, excepting interventional procedures (like percutaneous coronary angioplasty) that can expose patients to substantially higher radiation risk.

Biological effects of ionizing radiation in a human organism can be divided into two categories: deterministic and stochastic [3, 4]. The main mechanism of the former is death of an essential fraction of cells in a tissue or an organ caused by irradiation of a part or a whole organism. This damage cannot be repaired completely and spontaneously. Such effects are observed only when doses exceed threshold values for the tissue in question. The thresholds vary between 0.2 and several grays for various tissues and organs. Those effects are never seen after application of a proper activity of a radiopharmaceutical used for diagnostic purpose.

Stochastic effects are those which appear in irradiated populations with incidence proportional to the dose; they are also called probabilistic. Stochastic effects result from damage to somatic and reproductive cells. Those cells which survive irradiation can become carriers of mutations caused by damage to DNA. Effects of such a damage can lead to development of malignant neoplasms, and if the damage was located in reproductive cells — to hereditary effects (which can appear in next generations). There is a common opinion (although contested by some investigators) that at low and intermediate doses the probability of induction of malignant tumors and hereditary effects is proportional to the dose of radiation, without threshold. The risk of hereditary effects from ionizing radiation was so far evaluated only from studies on animals of different species. The direct data for humans exposed to low doses are not available at present. The ICRP evaluated the respective probability of the hereditary risk as being very low, 0.2% per Gy (or 2×10^{-6} per mGy) up to the second generation [7]. This is less than one tenth of the risk of fatal carcinogenesis following irradiation [7].

The mortality risk from malignant neoplasms, induced by ionizing radiation from diagnostic procedures in nuclear medicine has been estimated from extrapolations of the effect of doses in the order of 0,5–1,0 Sv, observed in several epidemiological stu-

Table 1. Effective doses to patients obtained from radiopharmaceuticals used in nuclear medicine cardiac studies [acc. to 8–11]

Procedure	Radiopharmaceutical	Administered activity [MBq]	Effective dose [mSv]
Perfusion scintigraphy of myocardium (SPECT)	99mTc-MIBI (rest)	740	6.7
	99mTc-MIBI (stress)	740	5.8
	99mTc-tetrophosmin (rest)	740	5.6
	99mTc-tetrophosmin (stress)	740	5.2
	201Tl chloride	74	16.0
Perfusion scintigraphy of myocardium (PET)	82Rb rest/stress	2 × 740	5.0
	13N NH3 rest/stress	2 × 550	2.2
	H215O rest/stress	2 × 740	1.4
Gated blood pool study (planar,SPECT)	99mTc-labelled red blood cells	740	5.2
Viability study of myocardium (PET)	18F fluorodeoxyglucose	370	7.0

Table 2. Effective doses to patients in selected radiological procedures applied in cardiology [acc. to 12, 13]

Procedure	Mean effective dose [mSv]	Doses quoted in literature (range) [mSv]
Posterior and lateral chest radiogram	0.1	0.05–0.24
Chest CT	7	4.0–18.0
Coronary calcium score	3	1.0–12.0
Coronary CT angiography*		5.0–32.0
Invasive coronary angiography (dignostic)	7	2.0–15.8
Percutaneous coronary intervention or radiofrequency ablation	15	7.0–57.0

*Range of doses taken from literature published before 2007. Introduction of a new generation equipment and modern techniques of examination reduced the effective dose even below 5 mSv (for this reason mean effective dose is not presented)

dies. So called nominal probability coefficient for fatal cancer published by ICRP equals 4% per Sievert [7]. A widely accepted linear non-threshold model of incidence of malignant tumours in relation to radiation dose leads to values about 1:400 000 per mSv. This means that death risk from fatal cancer caused by patient irradiation during stress and rest perfusion study of myocardium (effective dose 10 mSv) could be estimated as lower than of 0.1 per mille. For better understanding of this risk: if a large population of people was exposed to analogous radiation dose, malignant neoplasms leading to death could be additionally expected in less than 0.1 pro mille of this population. One should remember that normal mortality from spontaneous malignant tumours in human populations amounts to 20–25% [3, 12].

In addition, one should also remember that potential effect of the discussed nature is delayed after irradiation. The shortest delay time of radiation induced leukemia equals 2–3 years (the average delay is 7 years) and for malignant solid tumours the analogous time intervals are 10–15 years (mean 20 y) [3].

In addition, the risk declines with age. The probability of cancer induction after exposure at the age of 60 years is 5 times lower than that after exposure at 20–40 years [3].

The sensitivity to radiation in utero life and the first decade after birth is 2–3 times higher than that given above for the whole population [3].

A nuclear medicine study, if conducted in a proper way and undertaken due to reasonable indications, carries potential health gains for a patient, exceeding by orders of magnitude the negative effects for health and life. In other words, refraining from a well motivated nuclear medicine procedure can be a source of incomparably higher risk to a patient.

Conclusion

Nuclear medicine diagnostic procedures, including the cardiological ones, are accompanied by a very small radiation risk. Nevertheless, patient exposure to ionizing radiation should observe following conditions [4]:

1. Proper justification of a well selected nuclear medicine procedure;
2. Optimization of patient protection, i.e. exposure to possibly low doses but providing appropriate procedure and radiopharmaceutical activity to obtain useful result;
3. Avoiding nuclear medicine procedures in pregnant women (due to higher sensitivity of the embryo and fetus to ionizing radiation), especially that in many clinical situations there is a possibility to apply in women at that age other diagnostic studies that do not expose patients to ionizing radiation (like e.g. echocardiography).

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