Methods and measurements in radiation synovectomy with ^{90}Y of knee joint dosimetry

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Abstract. Radioisotope synovectomy is based upon an yttrium-90 colloid injected into the knee joint (the usual injected activity ranges from 111 MBq to 222 MBq per joint). Execution of the procedure needs participation of a nuclear medicine specialist as well as an orthopedist or a rheumatologist and a technologist who prepares radiopharmaceuticals. All of these participants are exposed to ionizing radiation. The ionization doses for patients and personnel are dependent not only on the activity injected, but also on the method and process of injection as well as the radioactivity measurement procedure used. In the experiments performed, a significant influence of the biodistribution of the radioisotopic substance on the exposure results has been observed.

Key words: Yttrium-90 • dosimetry • synovectomy • radiation protection • gammacamera • knee joint

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Introduction

^{90}Y is one of the most frequently used radioisotopes in nuclear medicine radiotherapy [13]. The production of this isotope is based upon neutron bombardment of ^{89}Y in a nuclear reactor [8, 10]. Final result is a step down process of $^{90}Y/^{90}Sr$ radioactive chain reaction:

$$(1) \quad ^{90}Sr \xrightarrow{\beta^-(0.54 MeV)} {}^{90}Y \xrightarrow{\beta^-(2.28 MeV)} {}^{90}Zr \ [12]$$

^{90}Y decays to stable ^{90}Zr through the emission of high energy β^- radiation (E_{max} = 2.28 MeV) [5] with a medium energy of 0.936 MeV [8]. The deposition of radionuclide or radiopharmaceutical in a tissue is based on the specific receptor uptake in a two-step process, i.e. first preliminary binding followed by a stable build in process. It is a radioelement with a 64.1 h half-life with an average penetration of beta radiation of 3.6 mm into soft tissues (maximum 11 mm) and with an average penetration into the cartilage of 2.8 mm (maximum 8.5 mm).

Radiosynovectomy (RS) is mainly used in case of chronic joint inflammation which is resistant to cure by the conventional methods. Treatment with ^{90}Y in RS is recognized as a safe, quick and effective method for patients suffering from persistent inflammation of the pulp membrane. In the pulp membrane RS, the radioisotope is concentrated in a colloid suspension marked with an isotope [2]. The most important factor for RS treatment is the size of the molecule which should remain in the range of 5 to 20 μm. In other cases it causes a radioisotope diffusion out of knee and causes irradiation of other organs.

The effectiveness of this method of treatment is measured by pain reduction, and by maintaining knee activity and functionality. RS is based upon an intra-cavity knee injection with colloids or attached radionuclide beta emitters and their transfer to pulp membrane.

Dosimetry deals with measurement and calculation of radioisotope doses as well as defining radioionization emission parameters which have an effect on living tissue [5]. According to ICRP classification, there are three types of radiation exposure risks, i.e. medical exposure, occupational exposure of medical personnel and finally population exposure [6]. In the case of radio exposure it is necessary to define emission properties of the isotope used. ^{90}Y is a β^- emitter, so it exerts secondary radiation called Bremsstrahlung whose properties depend on a kind of β-radiation properties a shape of a surrounding material, the volume in a syringe, the material and density of the container or ionization chamber geometry.

According to Zanzonico PB *et al*. Bremsstrahlung must not be omitted because it is not indifferent for patient dosimetry [14]. But Leichner PK *et al*. did not implement Bremsstrahlung radiation in the calculation of dose absorbed, because in soft tissue only about 1% of the beta particle energy is converted to Bremsstrahlung. The authors believe that in consequence the Bremsstrahlung absorbed in a tumor and healthy tissue has been said to be neglected in comparison to the dose of β^- particle emission [11].

An essential element of therapy security is the value of dose conceived by other organs. A blood sample was used to evaluate the time of isotope activity within the bone marrow. Doses absorbed by healthy organs have been evaluated. It turned out that the measured values were much lower than the agreed respective safe boundaries [9]. Measurements of urine samples performed by Frassen M *et al*. showed only 3% of the total activity injected in probes collected for a period of 48 h after injection of ^{90}Y colloid into a knee joint [7]. There were also examinations performed with the aim to evaluate total dose during RS using ^{90}Y-silicate colloid for patients and medical personnel as well. The results presented above are lower than the alternative RS results used to treat inflammation of knee membrane. Material used such as ferric hydroxide macroaggregate marked with dysprosium-165 (^{165}Dy-FHMA) or holmium-166 (^{166}Ho-FHMA) [1]. Edmonds J *et al*. claim better results in clinic cure by use of ^{165}Dy over therapy with ^{90}Y [3].

From the publications presented above there are contradictory results on the same therapy methods.

As a result of what was presented above, an independent examinations in the field of patient and medical personnel dosimetry in the usage of ^{90}Y has been undertaken. Personal dose equivalent in the body and kinetic energy released per unit air mass (air KERMA) was measured for patients and medical personnel as well.

Limit dose equivalent values are defined by the Atomic Law and the safety of RS experiments is obeyedin accordance with them [4].

Material and methods

Dosimetry measurements were performed in the three medical centers: Clinical Medical Center of Gdańsk Medical Academy, City Hospital in Gdynia, Central Clinical Hospital of the Ministry of Internal Affairs and Administration in Warsaw. There were 19 patients and 12 persons of medical staff involved (physician and radiological personnel). The injected activity used was in the range of 174 MBq to 220 MBq (yttrium citrate, CIS bio international, Paris, France). The patients qualified for treatment due to conditions such as rheumatoid arthritis (8), psoriatic arthropathy (3), serosynovitis (4), joint effusion following knee injury (3) and hemophilic arthropathy (1). Thermoluminescence dosimeters were used to evaluate:

- personal dose equivalent at 0.07 mm depth in the body Hp(0.07) [mSv] – dosimeter type PI-01,
- personal dose equivalent at 10 mm depth in the body Hp(10) [mSv] – dosimeter type DI-02,
- kinetic energy released per unit air mass (air KERMA) K_a [mGy] – dosimeter type DS-04.

Measurements of dosimeters PI-01, DI-02 and DS-04 were performed at the Laboratory of Individual and Environmental Dosimetry of the Institute of Nuclear Physics in Kraków, Poland.

Each patient taking part in this study was equipped with a dosimeter type: PI-01 (attached immediately after injection close to the place of injection), DI-02 (placed under clothing on the patient's chest) and DS-04 (0.5 m to 1 m over the patient's bed). Dosimeter exposure to the patient's activity was measured for a minimum of 48 h. Special instructions had been prepared for patients to explain how to deal with attached dosimeters and a questionnaire helping to understand the process of dosimetry exposure (patient's compliance). Additionally, all medical records were collected for each patient.

Patients were divided into groups according to their illness.

For proper assessment of radiation emitted by a radionuclide, its energy spectrum and reduction of radiation were established using gammacamera analysers. The radioisotope was placed in different media (water or cupper plates of different thicknesses) as well as using various collimators (low energy general purpose and high energy).

Knee joint scintigraphy using gammacameras was performed in two out of three hospitals.

In Gdańsk, three patients had static spot studies (5 min) which have been performed using a single head Diacam gammacamera (Siemens, Erlangen, Germany) with a low energy all purpose collimator.

In Warsaw, scintigraphy was performed on dual head gammacamera Ecam (Siemens, Erlangen, Germany) with high energy collimators. A 15 min SPECT study 2 h after injection was performed on three patients (Fig. 1). A 10 min spot study 20 min after injection was performed on five patients. A whole-body scan 72 h after injection had been performed on one patient.

Both gammacameras were equipped with a 3/8 inch crystal (NaI) with 59 photomultipliers, but with different detector electronics for image processing so, the final image properties are different (resolution and

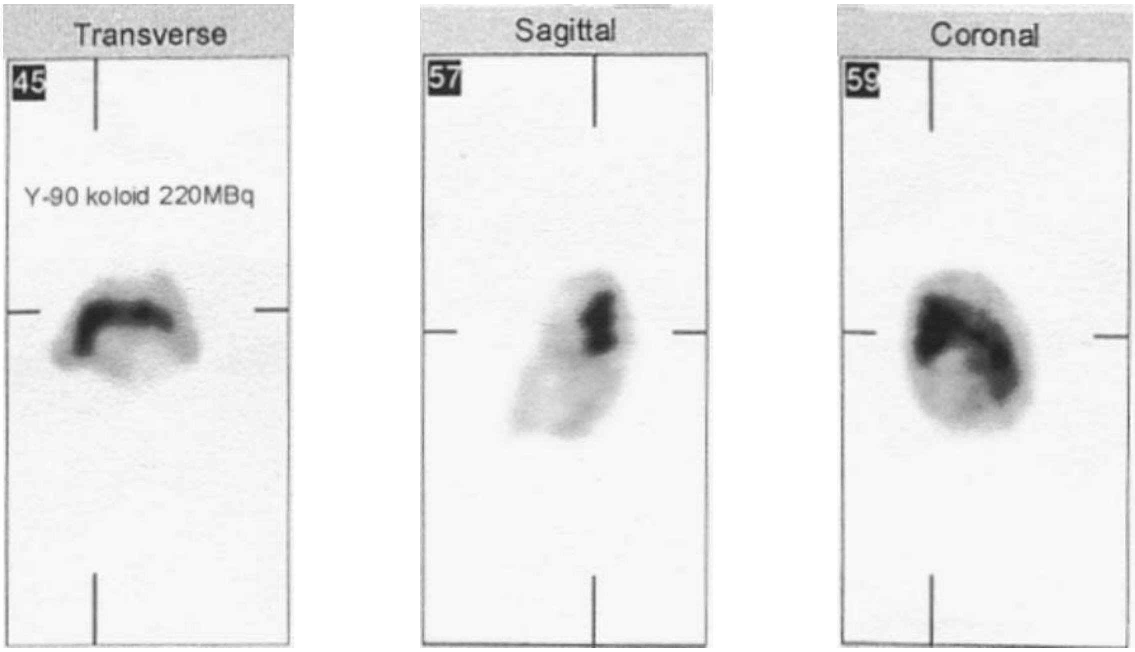
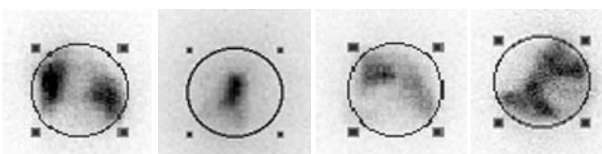


Fig. 1. Examples of images of the joint radioisotope distribution (SPECT, 220 MBq, high energy collimator).



a b c d

Fig. 2. Image processing with ROI. a – Rheumatoid arthritis (192 MBq, high energy collimator); b – psoriatic arthropathy (185 MBq, low energy collimator); c – serosynovitis (192 MBq, high energy collimator); d – haemophilic arthropathy (174 MBq, high energy collimator).

sensitivity). Diacam gammacamera is equipped with a computer system based on Icon 9.5 (Macintosh OS7-Open System). Ecam gammacamera is equipped with a computer system based on Esoft (Siemens language powered by Windows XP). Thanks to the Dicom Format of images, the data between Icon and Esoft can be exchanged and reprocessed.

Final image processing was based on drawing a ROI (region of interest) in a form of a circle with a radius of 15 pixels covering the joint and performing statistical calculations (mostly amount of counts within a region) depending on patient clinical data (Fig. 2).

Before RS examination, the medical personnel involved was equipped with a PI-01 dosimeter (ring on a tip of the index finger of the operator, on the right hand for right-handed person and on the left hand for a left-handed person) placed under the medical glove, DI-02 dosimeter on a gown in the chest region and DS-04 in the medical personnel environment.

Results and discussion

Dosimetry of patients

Patients who agreed to take part in the dosimetry procedure were given an informed consent and filled out a questionnaire about the measurement process. They agreed to obey rules described in the instructions given to them prior to the treatment process. For each group of patients with a particular medical condition, mean measured values have been calculated for each type of dosimeter, i.e. PI-01, DI-02 and DS-04 (Table 1). A zero value has been given to measurements below sensitivity threshold.

A personal dose equivalents Hp(0.07) showed that the lowest values were measured for rheumatoid arthritis in contrary to the highest absorbed values in air. The opposite situation was found in the patients with psoriatic arthropathy. These values were compared with different parameters such as body weight, age and medical history. Calculations of personal dose equivalents of the measured doses showed larger values for BMI higher than 25 (body-mass index) or, in the cases when the treatment started not earlier than two years

Table 1. Mean values of the dosimeter readouts: values have been normalized to 1 MBq of injected radiopharmaceutical activity

		Kind of illness			
		Rheumatoid arthritis (8 knees)	Psoriatic arthropathy (3 knees)	Serosynovitis (4 knees)	Joint effusion following knee injury (3 knees)
Thermoluminescence	PI-01 – Hp(0.07) [μSv]	36	104	63	97
dosimeters	DI-02 – Hp(10) [μSv]	0.6	0.6	0.7	0.8
(values)	DS-04 – K_a [μGy]	0.8	0.6	0.3	1

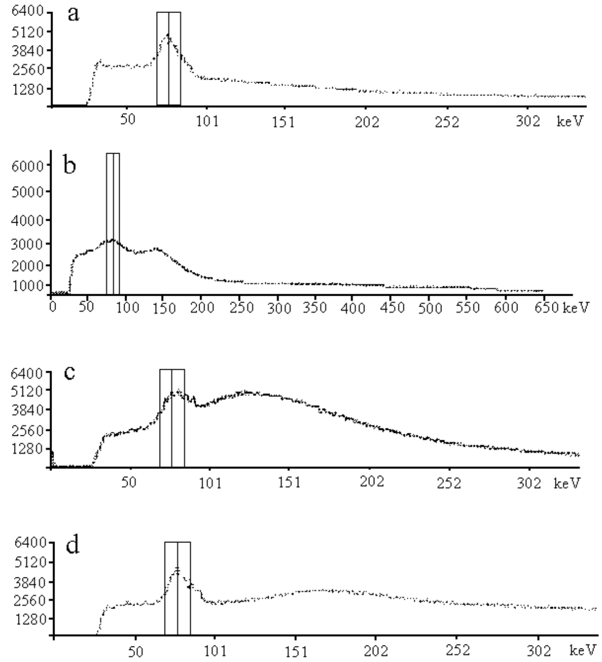


Fig. 3. Spectrum of ^{90}Y obtained by the usage of a gammacamera multichannel analyzer. a – Without collimator; b – with high energy collimator; c – with low energy collimator, isotope covered (attenuation) with 60 0.2 mm thick copper tiles; d – with low energy collimator, isotope submerged in a 5 cm layer of water.

after the start of symptoms, as well as in the case of patients older than 40 years.

It may be hypothesized that increased emissions from the patient's body was received by patients with higher inflammation activity in the joint. This could be a result of higher isotope backscattering into the organism.

Changes of the ^{90}Y spectrum in different media and at different distances has been analyzed. This lead to the setting of an analyzer of the gammacamera parameters to facilitate measurement results such as the 77 keV peak value and 20% window (Fig. 3). These gammacamera parameters were used for scintigraphic examinations.

For one patient with rheumatoid arthritis, a whole-body examination following the radiopharmaceutical administration (Fig. 4) has been presented.

Quantitative scintigraphy has shown that the activity of the knee made up 30% of the whole-body activity. The activity in the joint area after 72 h injection of the radiopharmaceutical solution was 2.6 times lower than that at the moment of injection. The obtained value was a combined action of the isotope biodistribution in the whole organism (radiopharmaceutical diffusion out of the knee region, metabolism and elimination by urine extraction) as well as the radioisotope ^{90}Y life half-time. Counts of statistics for scintigraphic images of the joint achieved during 5 min for various illness and different gammacameras are presented in Table 2.

A comparison of counts in a selected region covering the joint and readouts of the dosimeters type PI-01 was performed. The analysis showed a correlation between the counts acquired and Hp(0.07).

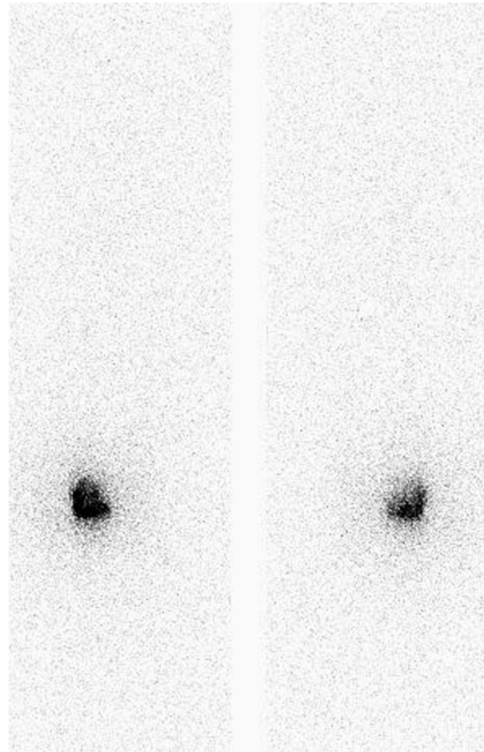


Fig. 4. Whole-body scan after 72 h injection of a radiopharmaceutic (192 MBq, high energy collimator).

Dosimetry of medical personnel

The medical team taking part in the RS examination made up of an orthopedist and/or physician specialist in the nuclear medicine as well as technical personnel. They utilized various methods of radiation protection (syringe shields, protective gloves and lead building blocks). Measured mean values for three types of dosimeters for medical personnel are presented in Table 3.

The results from readings of the dosimeter type PI-01 presented in Table 3 show that the use of gloves only resulted in 8 times higher absorbed doses in comparison to the technical personnel using syringe shields. In the case of physicians this value was 1.5 times higher. Limitation of the amount of examinations of RS with ^{90}Y performed by each working group can be established if only results presented above are implemented.

RS experiments were performed by one person or a team of two persons. For each medical personnel, an optimal amount of RS procedures should be limited to fourteen per week when two people are needed, but in the case of maximum values of measured doses the amount of examinations has to be limited to two per week. In the case of one person performing RS the amount of examinations has to be limited to six per week, but in the case of maximal absorbed doses measured the limit should lowered to two examinations per week.

Conclusions

The results on RS dosimetry presented above show that there is no need to hospitalize patients. The results show a high value of gammacamera scanning in assert-

Table 2. Mean values of the counts. Values have been normalized to 1 MBq of injected radiopharmaceutical activity

	Diacam	Ecam
	Low energy collimator (counts/5 min/1 MBq)	High energy collimator (counts/5 min/1 MBq)
Rheumatoid arthritis	774 ± 33	352 ± 15
Psoriatic arthropathy	1092 ± 48	586 ± 23
Serosynovitis	–	413 ± 19

Table 3. Mean values of the dosimeter readouts. Values have been normalized to 1 MBq of injected radiopharmaceutical activity

		Medical personnel	
		Physician (6 persons)	Technical (6 persons)
Thermolumenescence dosimeters (values)	PI-01 – Hp(0.07) [μSv]	1	3
	DI-02 – Hp(10) [μSv]	0.8	1
	DS-04 – K_a [μGy]	0.7	–

ing the patient dosimetry after RS. Scintigraphy of the knee joint in a given moment of the therapy makes continuous monitoring of the accumulation process of radiopharmaceutical possible. It gives very useful information for a physician. Using this information he can foresee the results of the therapy undertaken. Formulation of the biodistribution of radiopharmaceutical in the patient's body requires more scintigraphic experiments to be performed.

The results of the comparative experiments performed on the patients presented above demonstrated that the measurements obtained with dosimeters can be replaced by the results of scintigraphy (cheaper and easier access by the Departments of Nuclear Medicine).

Individual dosimetry of the medical personnel performed in Poland proved that the standard four RS procedures per month is a save treatment process.

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