Personal dose equivalent Hp (0.07) during 68 Ga-DOTA-TATE production procedures

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Research Article

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Abstract

Objective: The work presents the exposure of hands of the personnel of a nuclear medicine department who prepare and administer ^{68}Ga-DOTA-TATE.

Materials and methods: Dosimetry measurements were performed during three one-week sessions by using high-sensitivity thermoluminescent detectors. Radiochemists and nurses were included.

Results: The greatest exposure to ionizing radiation is in the non-dominant left hand of radiochemists and nurses. The maximum $H_p(0.07)/A$ value of 49.36 ± 4.95 mSv/GBq was registered for radiochemists during the ^{68}Ga-DOTA-DATE activity dispensing procedure. For nurses performing the radiopharmaceutical injection procedure, the maximum value of $H_p(0.07)/A$ was recorded, amounting to 1.28 ± 0.13 mSv/GBq. The dispensing of the dose of ^{68}Ga-DOTA-TATE accounts for approximately 60% of the exposure of radiochemists' fingertips.

Conclusions: The authors of the study recommend routine placement of a ring dosimeter on the middle finger of the non-dominant hand of radiochemists and nurses.

Introduction

It has been known for a long time that in the case of nuclear medicine procedures, the hands of personnel are the most exposed. This is because the employee not only carries out the procedures of producing the radionuclides themselves, but also labels chemical compounds with these radionuclides in order to obtain radiopharmaceuticals or injects the prepared preparation into the patient’s body (Stuarto 1990; Chiesa et al. 1997; Williams et al. 1990; Batchelor et al. 1991; Dhanse et al. 2000; Kubo & Mauricio 2014; Sandouqa et al. 2011; Leide-Svegborn 2011). The occupational groups most affected by this exposure are radiochemists and nurses (Meisenheimer et al. 2020; Wrzesień and Napolska 2015; Wrzesień et al. 2019; Wrzesień and Albiniak 2016; Wrzesień 2018; Vanhavere F et al. 2012). Over the last dozen or so years, a lot of attention in scientific publications has been devoted to the exposure of the staff’s hands when performing tasks involving radionuclides (Sans-Merce et al. 2011a; Breeman et al. 2005; Wrzesień et al. 2008; Carnicer et al. 2011; Sans Merce et al. 2011b). However, it is important to mention that nuclear medicine involves a multitude of radionuclides and procedures that are carried out, for example, as part of the production and quality control of radiopharmaceuticals. In such a case, the method of obtaining the radionuclide to be subsequently used for the preparation of the radiopharmaceutical should be taken into account. We are talking about nuclear reactors, cyclotrons and short-lived nuclide generators.

Short-lived nuclide generators, in particular the ^{99}Mo/^{99m}Tc generator, the main source of the ^{99m}Tc radionuclide, is considered to be an uncomplicated procedure that allows to obtain one of the most commonly used diagnostic isotopes in nuclear medicine. Compared to the ^{99}Mo/^{99m}Tc generator, the operation of another ^{68}Ge/^{68}Ga short-lived nuclide generator seems much more complicated. Therefore, the question remains whether the implementation of the procedures to obtain the ^{68}Ga radionuclide as a result of operating the ^{68}Ge/^{68}Ga generator indicates greater radiological exposure for personnel performing elution and labelling of chemical compounds using the ^{68}Ga radionuclide.

Nowadays the ^{68}Ge/^{68}Ga generator and DOTA conjugated peptides are not registered on the market. Therefore, they must be prepared taking into account national regulations as well as the Good Radiopharmaceutical Practice (GRPP) described in the detailed guidelines of the European Society for Nuclear Medicine (EANM) (Piciu 2012; cGRPP; Elsinga et al. 2010; ISO 1999).

Wrzesień and Albiniak in their publication from 2019, in which the exposure of the eye lenses of nuclear medicine staff related to the preparation and injection of the DOTA-TATE radiopharmaceutical labelled with ^{68}Ga was discussed, underline that manual operation of the ^{68}Ge/^{68}Ga generator – ^{68}Ga sources, as well as labelling procedures and activity separation may be a source of exposure of the eye lenses, which may consequently lead to exceeding the annual dose limit for the eye lens. Therefore, it seems natural to ask if similar conclusions will be reached as a result of analysis of the exposure of the hands of the staff performing procedures with the use of the ^{68}Ga radionuclide and the ^{68}Ga-DOTA-TATE radiopharmaceutical labelled with it.

Material And Methods

Dosimetric measurments were performed with the use of high-sensitivity thermoluminescent detectors (TLDs) (LiF: Mg, Cu, P) in one (out of three) national nuclear medicine centres, where procedures for the diagnosis of neuroendocrine tumors using PET technique are performed. Five radiochemists and four nurses participated in three-week measurement sessions. Before starting the measurements, the detectors were annealed according to the manufacturer's recommendations and each was individually vacuum-packed in foil. The detectors prepared in this way were placed on the workers' fingertips. The necessary condition for the implementation of dosimetric measurements was the lack of influence of the presence of detectors placed on the fingertips on the time and efficiency of the procedures performed by radiochemists and nurses.

A gamma radiation source – ^{137}Cs (^{60}Co/^{137}Cs irradiator) was used to calibrate the detectors in the Secondary Standards Laboratory. Dosemeters were calibrated in accordance with ISO 4037-3 (ISO 1999) in the range from 0.05 to 30 mGy as the air kerma. The $H_p(0.07)$ for fingers was calculated taking into account the conversion coefficient $h_{pK}(0.07)$, given in the ISO International Standard. A rod phantom - ISO 2000 - was used as well. In the dosimetric measurements, background radiation was taken into account. The thermoluminescent detectors were read using the RA '04 reader, manufactured by the Polish company Mikrolab.

Procedures for obtaining and injection of ^{68}Ga-DOTA-TATE

The ^{68}Ga-DOTA-TATE procedure begins the ^{68}Ge/^{68}Ga generator elution process. The second stage of labelling the preparation is preceded by the preparation of a column containing ^{18}C and 2 cm of saline and 1 ml of 96% ethanol used to activate the column. A detailed description of the steps involved in the procedures to obtain the radiopharmaceutical ^{68}Ga-DOTA-TATE is presented in publication titled *^{68}Ga-DOTA-TATE - a source of eye lens exposure for nuclear medicine department workers* (Wrzesień and Albiniak 2018).

Statistical analysis

The measurements performed in the study are H_p(0.07)/A (normalised personal dose equivalent). The values of activity (A) used were the actual values for each procedure that was carried out.

Results

Figure 1 presents H_p(0.07)/A values recorded by thermoluminescent detectors for left and right hands of radiochemists and nurses.

The maximum value of H_p(0.07)/A – 49.36 ± 4.95 mSv/GBq was recorded for the index finger of the left hand of Radiochemist 1 during the procedure of dispensing a dose of the radiopharmaceutical. For nurses the biggest H_p(0.07)/A value – 1.28 ± 0.13 mSv/GBq was recorded for the thumb of the left hand of Nurse 1.

The preliminary analysis of the results also showed that the dosimetric ring should be worn by staff on the left hand, since for both groups of workers higher doses were recorded for the left hand.

Figure 2 shows the activity used in individual production stages of ^{68}Ga-DOTA-TATE and during the injection of the radiopharmaceutical.

The highest activity value of the radiopharmaceutical at which radiochemists worked was recorded for the elution stage – 0.90 GBq. The lowest activity was recorded during the work of nurses during the injection of the radiopharmaceutical – 0.26 GBq.

Fingertip exposure during ^{68}Ge/^{68}Ga generator elution

Figure 3 shows fingertip exposure of the left of a radiochemist during the ^{68}Ge/^{68}Ga generator elution. The authors decides not to present the dose values for fingertips of the right hands of radiochemists due to the fact that the highest value recorded for the right hand (for the thumb of Radiochemist 1 - 0.26 ± 0.11 mSv/GBq) is 15 times smaller than the highest value recorded for the fingers of the left hand (index finger of Radiochemist 4 - 4.08 ± 0.02 mSv/GBq).

The highest value of H_p(0.07)/A for the left hand was recorded for the index finger of Radiochemist 4 and it was 4.08 ± 0.02 mSv / GBq. The average value of the activity with which the chemist worked was 0.65 GBq.

Labelling the pharmaceutical with the ^{68}Ga radionuclide

For the labelling procedure, the highest values of the normalized doses was recorded for the fingertips of the Radiochemist 2 and Radiochemist 5. For the rest of the staff $H_p(0.07)/A$ values did not exceed the value of 1.16 ± 0.55 mSv/GBq for the fingertips of the left hand and 0.55 ± 0.10 mSv/GBq for the right hand. Figure 4 shows the results for the two most exposed workers.

The biggest normalised $H_p(0.07)$ dose value was recorded for the middle finger of the left hand of Radiochemist 5 and it was 11.56 ± 3.54 mSv/GBq. In the case of Radiochemist 2, the highest normalized $H_p(0.07)$ value applies to the little finger of the left hand – 4.54 ± 1.61 mSv/GBq. During the labelling procedure, the average activity was 0.46 GBq.

Dispensing the dose of radiopharmaceutical

In the case of the procedure of dispensing the dose of the radiopharmaceutical, the largest $H_p(0.07)/A$ value – 38.96 ± 10.40 mSv/GBq – was noted for the second finger of the left hand of the Radiochemist 1. The average activity during the procedure of dispensing the dose of ^{68}Ga-DOTA-TATE was 0.31 GBq.

Injection of ^{68}Ga-DOTA-TATE

The highest value of normalised $H_p(0.07)$ was registered for the thumb of the left hand of Nurse 1 at 1.28 ± 0.13 mSv/GBq. The mean value of the activity injected to the patient was 0.39 GBq. Measurements in this case show that the highest mean exposure of the right hand fingertips are about half the level of the exposure of the left hand fingertips.

Discussion

^{68}Ga is a radioactive isotope which is the basis of, among others, the radiopharmaceutical compound ^{68}Ga-DOTA-TATE. This isotope generates positrons in the decay process; the positrons, in the process of annihilation with electrons, transform into gamma radiation with an energy of 511 keV. These photons are the basis of positron emission tomography research. It should also be remembered that the process of annihilation, and more precisely its effect - gamma radiation - constitutes the main exposure to ionizing radiation for the hands of medical personnel working in the production and injection of this radiopharmaceutical.

First is elution, consisting in obtaining a radionuclide from the generator by eluting its column, ending with obtaining an eluate. The next step is the labelling process, i.e. combining the earlier obtained radioisotope with a chemical substance. Last step before injecting the radiopharmaceutical to the patient is the procedure of dispensing the dose of ^{68}Ga-DOTA-TATE. Figure 8 shows the percentage of the total exposure level for each production step of ^{68}Ga-DOTA-TATE for the left and right hand of radiochemists.

The obtained results show that in the case of production of a ^{68}Ga-DOTA-TATE, the procedure of dispensing the dose of ^{68}Ga-DOTA-TATE has the biggest impact on the exposure of the workers' fingertips. On the other hand, the lowest percentage of the $H_p(0.07)$ value was obtained in the elution process. It bears mentioning that according to Fig. 2, the highest activity values of the radioisotope with which radiochemists work are obtained during the process of generator elution, and the lowest activity during the procedure of dose dispensing. However, taking into account the fact that the radiopharmaceutical dose dispensing procedure is the most time-consuming process, in contrast to elution process which needs the shortest time to proceed, it can be said that the long duration of the procedure (in accordance with the basic principles of radiation protection) affects the higher values of radiation doses received by workers.

Authors compared hand exposure generated by working with isotopes and radiopharmaceuticals made with the use of radionuclide generators. For this purpose, the data of hand exposure resulting from working with the most popular radioisotope from radionuclide generators – ^{99m}Tc was used. It is worth noting that compared with ^{18}F or ^{68}Ga, ^{99m}Tc is a source of gamma rays with an energy of 144 keV. Nevertheless, its production, as is the case with any generator-derived product, includes the elution process, labelling and procedure of dispensing the dose of ^{68}Ga-DOTA-TATE. In Fig. 9, authors compared the percentage level of the total exposure value of the right and left hand for each procedure for the radiochemists during the production of ^{68}Ga-DOTA-TATE and ^{99m}Tc.

In the case of procedures with the use of ^{99m}Tc, the biggest percentage impact in Hp(0.07)/A values was registered during the labelling procedure (84%) for the right hand of radiochemists. In the production process of a ^{68}Ga-DOTA-TATE the results are different. In this case the biggest percentage impact in a total $H_p(0.07)/A$ value was registered for the left hand of radiochemists during the procedure of dispensing the dose of ^{68}Ga-DOTA-TATE (61%). It is worth mentioning that in both cases the procedure which has the lowest impact (below 20%) in total exposure is the elution procedure.

Another popular radioisotope used in positron emission tomography is ^{18}F. Similar to ^{68}Ga, the annihilation process of positrons generates gamma rays that are the main source of workers' radiation exposure. However, ^{18}F-FDG is produced automatically. The only case of direct manual contact of the workers' hands with an open source of radiation is the quality control procedure of the produced ^{18}F-FDG. Hand exposures during the ^{68}Ga-DOTA-TATE dose dispensing procedure and ^{18}F-FDG routines were also compared. The results are shown in Fig. 10.

The procedure of dosing the radiopharmaceutical in the case of chemical compounds based on Tc-99m is a manual process. Time required to complete the procedure was presented in the publication written by Wrzesień (2018). In the case of ^{18}F-FDG, the procedure of dose dispensing is fully automatic. The small participation of the worker includes placing the syringe in the right place in the dispensing chamber before automatically filling the syringe with the appropriate radiopharmaceutical activity and removing the syringe from the dispenser after the dispensing process. Data presented in the Fig. 10 shows that in the case of the procedure of dose dispensing with use of ^{18}F-FDG, the left hand of the worker is more exposed than the right one, but the mean $H_p(0.07)$ value did not exceed 1mSv/GBq. For radiochemists performing the same procedure with ^{68}Ga-DOTATATE, the situation is quite different. In this case the left hand of workers is significantly more exposed. The mean values of Hp(0.07)/A exceeded 5mSv/GBq. For the right hand, the mean values of H_p(0.07)/A did not exceed 2mSv/GBq.

The final step in preparing the patient for examination with positron emission tomography is the injection of the radiopharmaceutical via intravenous route. The authors of this work compared exposure of the left and right hand fingertips of nurses who inject ^{68}Ga-DOTA-TATE with the results obtained for nurses who inject ^{18}F-FDG. Figures 11 and 12 presents the obtained results.

In this case conclusions are similar to the previous one. The left hand is the one more exposed in the injection process with ^{68}Ga-DOTA-TATE and ^{18}F-FDG. It is worth of mention that all nurses who took part in measurements were right-handed. For nurses during the injection of 68Ga-DOTA-TATE, the average H_p(0.07)/A values were twice as high for the thumb and index finger as for the nurses during ^{18}F-FDG injection. In the case of the left hand, the exposure resulting from working with a radiopharmaceutical based on ^{68}Ga is also higher for the thumb and middle finger.

Assessment of the annual exposure of workers associated with the radiopharmaceutical ^{68}Ga-DOTA-TATE

1. Assessment of exposure of the hands of radiochemists.

Assessment of exposure of fingertips was performed taking into account 1/3 of the number of working days per year (260) and the average exposure of individual measurement points, taking into account the average activity of the radiopharmaceutical estimated for individual procedures performed by staff using ^{68}Ga-DOTA-TATE.

With this assumption, the maximum annual exposure of 1030 mSv was obtained for the index finger of the left hand during the dosing of the ^{68}Ga-DOTA-TATE activity for individual patients. The minimum estimated annual value was 8 mSv for the middle finger of the right hand during generator elution. It is worth emphasizing, above all, that the maximum estimated exposure value is over 2 times higher than the annual dose limit, and moreover, work with the ^{68}Ga radionuclide is only part of the activity of employees who prepare other preparations based on ^{68}Ga (such as PSMA), but work with many other radionuclides, which consequently increases the exposure value on an annual basis.

2. Assessment of exposure of the hands of nurses.

The assessment of the annual exposure of nurses' hands was made based on the same assumptions as for radiochemists, namely 1/3 of the number of working days in a year (260) and the average exposure of individual measurement points, taking into account the average activity of the radiopharmaceutical estimated for individual procedures performed by staff using ^{68}Ga-DOTA -TATE.

As a result of estimating the values of annual exposure of nurses' hands, they range from 22 mSv to 76 mSv (in both cases it concerns the index finger of the left hand).

Conclusions

The production procedure of the radiopharmaceutical DOTA-TATE labelled with ^{68}Ga radionuclide is a series of manual procedures which include generator elution, labelling a chemical compound with a radioisotope, dosing of activity for the individual patients and injection of prepared portions of the preparation into individual patients. The analysis of the results of dosimetric measurements performed for individual production stages leads to the following conclusions:

- In the case of the production of ^{68}Ga-DOTA-DATE, the maximum $H_p(0.07)/A$ value of 49.36 ± 4.95 mSv/GBq was registered by one of the radiochemists during the radiopharmaceutical activity dispensing procedure. In the case of nurses performing the radiopharmaceutical injection procedure, the maximum value of $H_p(0.07)/A$ was recorded, amounting to 1.28 ± 0.13 mSv/GBq;

- In the case of both professional groups (radiochemists and nurses), the greatest exposure to ionizing radiation is in the non-dominant left hand. Consequently, the authors of the study recommend routine placement of a ring dosimeter on the middle finger of the non-dominant hand

- Comparison of the production procedures for ^{99m}Tc-labelled and ^{68}Ga-DOTA-DATE radiopharmaceuticals showed that the stage that has the greatest impact on the increase in exposure to ionizing radiation of workers' fingertips in the case of ^{99m}Tc-based radiopharmaceuticals is the labelling process. In the case of the ^{68}Ga-DOTA-DATE, the dispensing the dose of radiopharmaceutical accounts for approximately 60% of the exposure of radiochemists' fingertips;

- Greater complexity of procedures with the use of ^{68}Ga radionuclide causes greater exposure of the fingertips of employees performing these procedures, compared to the exposure of fingertips of staff performing procedures using the ^{99m}Tc radionuclide - including the short-lived radionuclide generator product.

- The maximum estimated exposure value of the fingertips includes the non-dominant hand and is twice the annual limit set at 500 mSv.

Declarations

Author's contribution: Małgorzata Wrzesień and Łukasz Albiniak were responsible for carrying out dosimetric measurements and processing the obtained test results. Also Małgorzata Wrzesień introduced changes and corrections to the manuscript. Łukasz Albiniak is responsible for the written manuscript and the presented figures. All authors reviewed the manuscript.

Conflict of interest: The authors declare that they have no conflict of interest.

Financial conflicts: The authors declare that have any financial conflicts.

References

1. Batchelor S, Penfold A, Aric I, Huggins R (1991) Radiation dose to hands in nuclear medicine. Nuclear Medicine Communications 12: 439–444
2. Breeman W.A, de Jong M, de Blois E, Bernard B.F, Konijnenberg M, Krenning E.P (2005) Radiolabelling DOTA-peptides with 68Ga. Eur J Nucl Med Mol Imaging 32:478–485
3. Carnicer A, Sans-Merce M, Baechler S, Barth I, Donadille L, Ferrari P, et al. (2011) Hand exposure in diagnostic nuclear medicine with 18F- and 99mTc-labelled radiopharmaceuticals – Results of the ORAMED project. Radiat. Measur 46: 1277–1282
4. Chiesa C, De Sanctis V, Crippa F, Schiavini M, Fraigola C.E, Bogni A, Pascali C, Decise D, Marchesini R, Bombardieri E (1997) Radiation dose to technicians per nuclear medicine procedure: comparison between technetium – 99m, gallium – 67 and iodine – 131 radiotracers and fluorine – 18 fluorodeoxyglucose. European Journal of Nuclear Medicine 24 (11): 1380–1389
5. Dhanse S, Martin C.J, Hilditch T.E, Elliott A.T (2000) A study of doses to the hands during dispensing of radiopharmaceuticals. Nuclear Medicine Communications 21: 511–519
6. Elsinga P, Todde S, Penuelas I, Meyer G, Farstad B, Faivre-Chauvet A, Mikolajczak R, Westera G, Gmeiner-Stopar T, Decristoforo C (2010) Radiopharmacy Committee of the EANM. Guidance on current good radiopharmacy practice (cGRPP) for the small-scale preparation of radiopharmaceuticals. Eur J Nucl Med Mol Imaging 37:1049–62
7. Guidelines on current good Radiopharmacy Practice (cGRPP) in the Preparation of Radiopharmaceuticals. http://www.eanm.org/scientific_info/guidelines/gl_radioph_cgrpp.pdf
8. International Organization for Standardization (ISO) (1999) X and gamma reference radiation for calibrating dosemeters and doserate meters and determining their response as a function of photon energy. Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence (Geneva: ISO) International Standard ISO- 4037-3
9. Kubo A. L. S. L, Mauricio C. L. P (2014) TLD occupational dose distribution study in nuclear medicine. Radiat. Meas 71: 442–6
10. Leide-Svegborn S (2011) External radiation exposure of personnel in nuclear medicine from ^{18}F, ^{99m}Tc and ^{131}I with special reference to fingers, eyes and thyroid. Radiat. Prot. Dosim. 149: 196–206
11. Meisenheimer M, Kürpig S, Essler M, Eppard E (2020) Manual vs. automated 68Ga-radiolabeling - a comparison of optimized processes. Journal of Labelled Compounds and Radiopharmaceuticals 63:162–173
12. Piciu D (2012) Nuclear Endocrinology. Springer 2012. ISBN 978-3-642-25013-2
13. Sandouqa A.S, Haddadin I.M, Abu-Khaled Y.S (2011) Hand equivalent doses of nuclear medicine staff in Jordan: Preliminary experimental studies. Radiat. Meas 46: 250–253

14. Sans-Merce M, Ruiz N, Barth I, Carnicer A, Donadille L, Ferrari P, Fulop M, Ginjaume M, Gualdrini G, Krim S, Mariotti M, Ortega X, Rimpler A, Vanhavere F, Baechler S (2011a) Recommendations to reduce hand exposure for standard nuclear medicine Procedures. Radiat. Meas. 46: 1330–1333
15. Sans Merce M, Ruiz N, Barth I, Carnicer A, Donadille L, Ferrari P, et al. (2011b) Extremity exposure in nuclear medicine: Preliminary results of a European study. Radiat. Prot. Dosim. 144:515–520
16. Stuarto E, (1990) Hand dose levels in Chilean nuclear medicine laboratories. Radiation Protection Dosimetry 34: 127–130
17. Vanhavere F, et al. (2012) Optimization of radiation protection of medical staff EURADOS Report 2012-02 Braunschweig
18. Williams D, Baird EE, Forster E (1990) Monitoring radiation dose to the hands in nuclear medicine: Location of dosemeters. Nuclear Medicine Communications 11: 271–277
19. Wrzesień M (2018) Simplicity or complexity of the radiopharmaceutical production process in the light of optimization of radiation protection of staff – 99mTc vs. 18F. Med Pr 69:317–327
20. Wrzesień M, Albiniak Ł (2016) Hand exposure of workers in 18F-FDG production centre. J. Radiol. Prot. 36: N67–76
21. Wrzesień M, Albiniak Ł (2018) 68 Ga-DOTA-TATE-a source of eye lens exposure for nuclear medicine department workers. J Radiol Prot. 38: 1512–1523
22. Wrzesień M, Napolska K (2015) Investigation of radiation protection of medical staff performing medical diagnostic examinations by using PET/CT technique. J. Radiol. Prot. 35:197–207
23. Wrzesień M, Olszewski J, Jankowski J (2008) Hand exposure to ionising radiation of nuclear medicine workers. Radiat. Prot. Dosim 130: 325–330
24. Wrzesień M, Albiniak Ł, Biegała M (2019) The structure of Hp(0.07) values obtained by the nuclear medicine personnel during 18F-FDG production and injection. Radiation Protection Dosimetry 184: 224–229

Figures

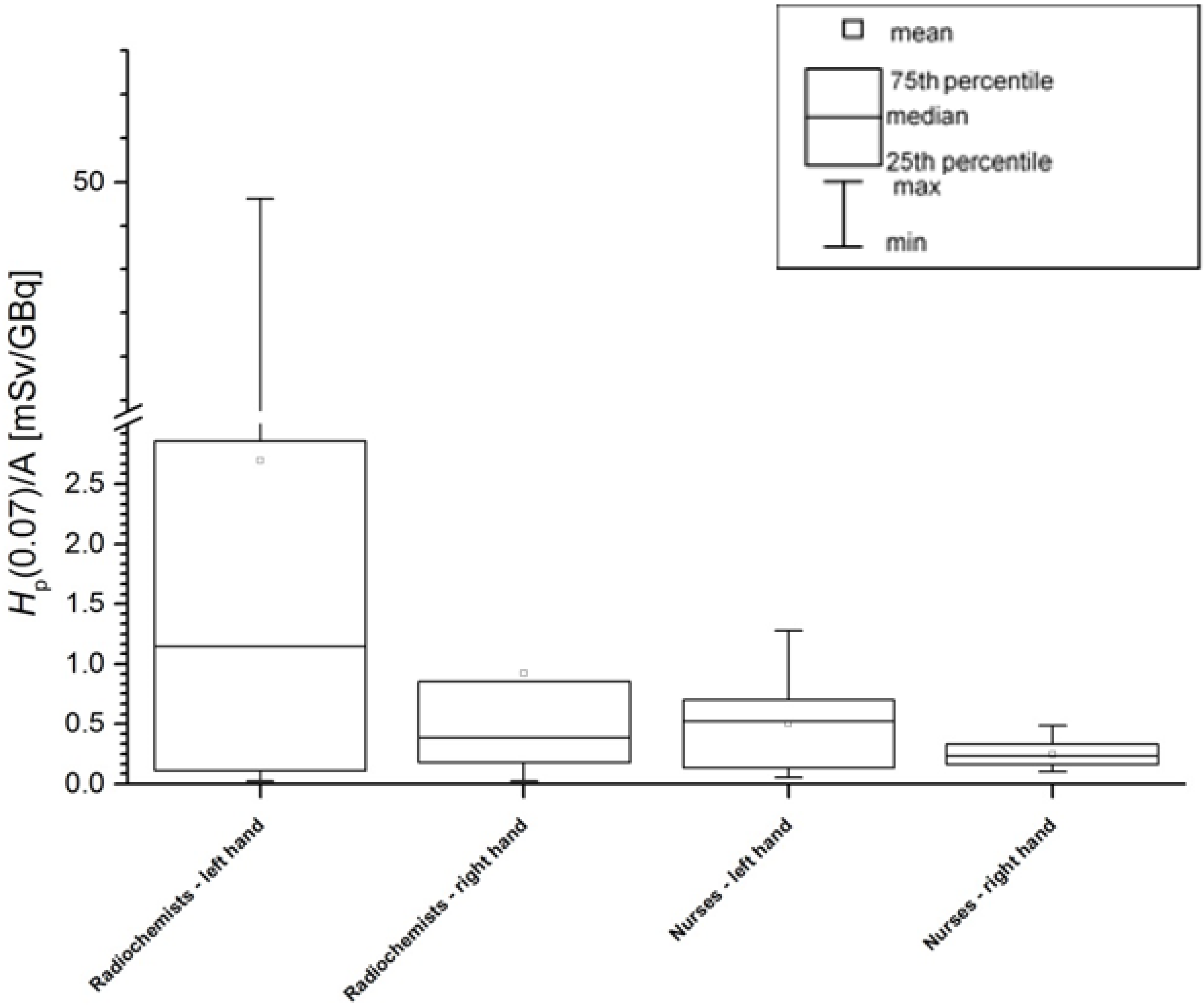

Figure 1

Exposure of the right and left hand for radiochemists responsible for the ^{68}Ga-DOTA-TATE production process and nurses performing injection of radiopharmaceuticals to the patients.

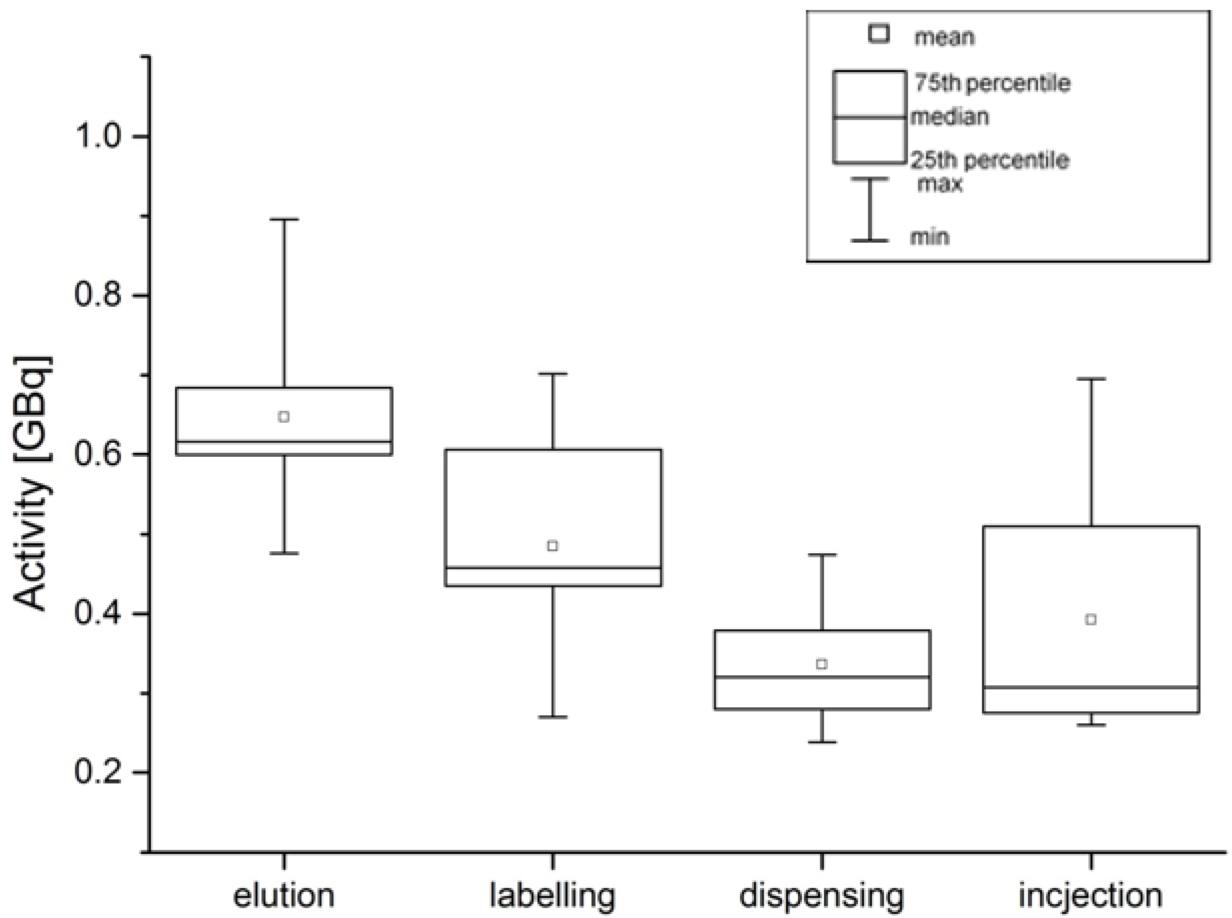

Figure 2

Activities of ^{68}Ga-DOTA-TATE at particular stages of production and during injection.

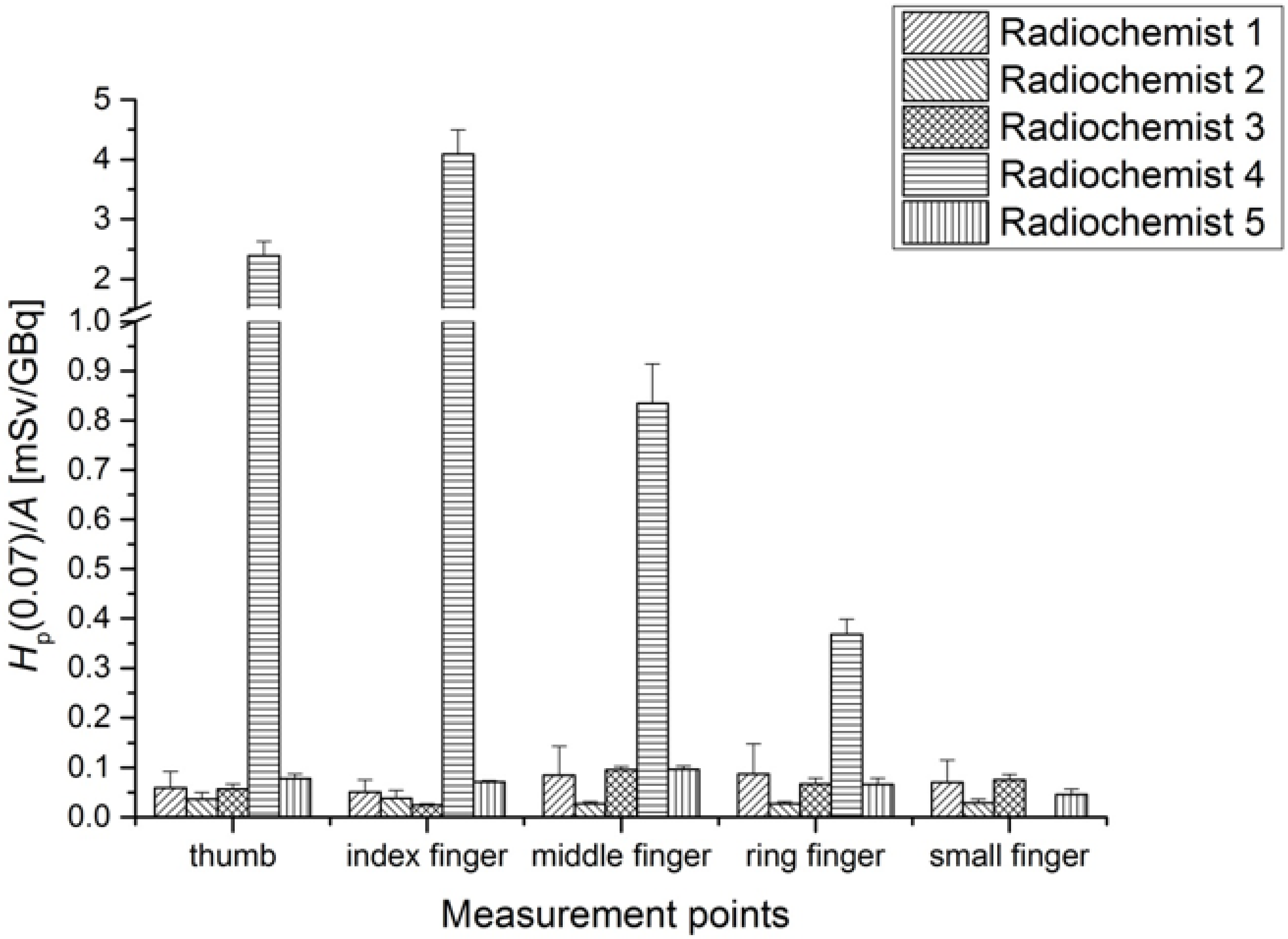

Figure 3

Average values of $H_p(0.07)$ per unit activity of ^{68}Ga-DOTA-TATE (with standard error) recorded at fingertips of both hands for employees performing the elution of the ^{68}Ge/^{68}Ga generator.

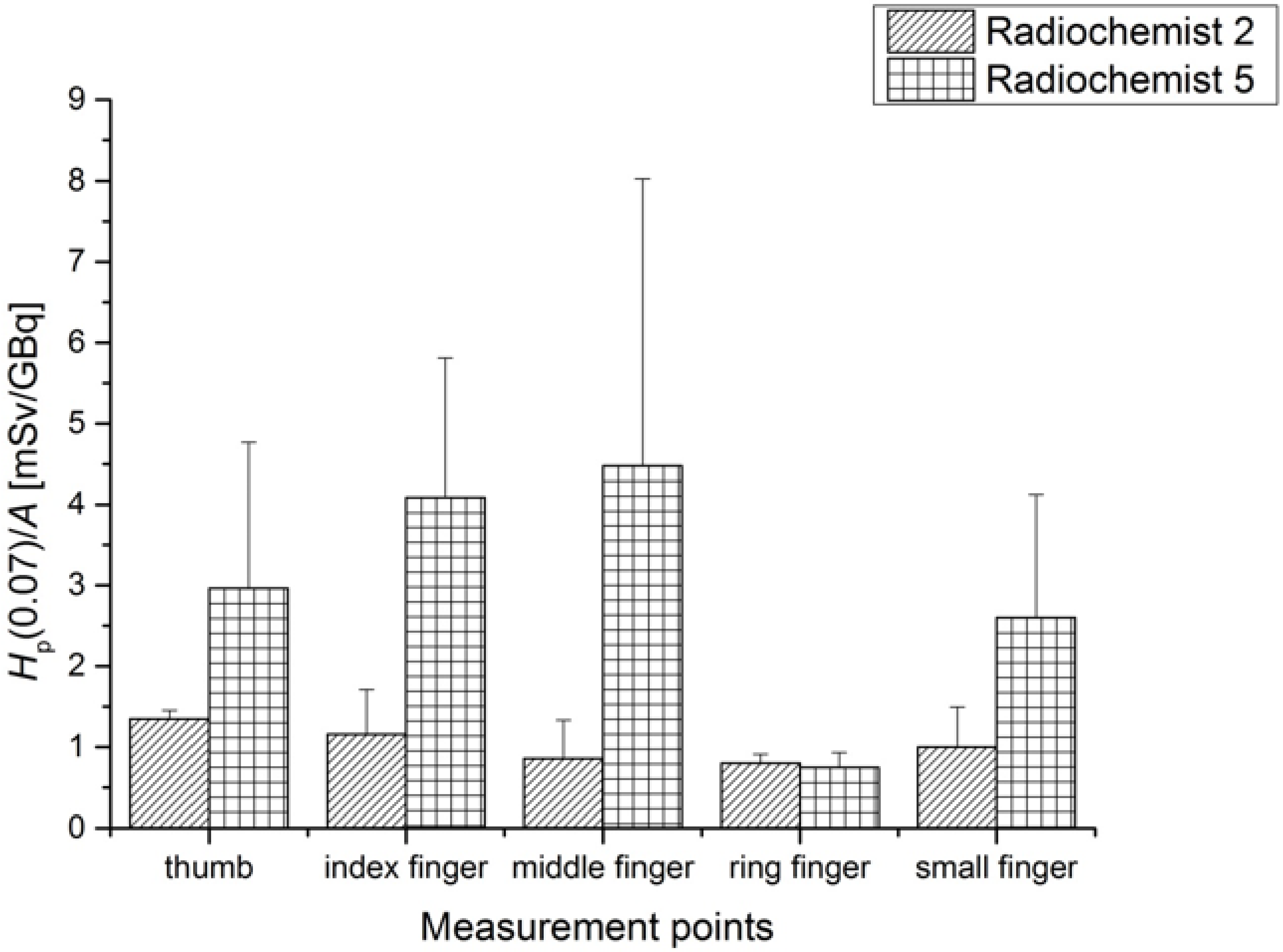

Figure 4

Average values of $H_p(0.07)$ per unit activity of ^{68}Ga-DOTA-TATE (with standard error) recorded at measurement points of the left hand for employees while labelling the pharmaceutical with the ^{68}Ga radionuclide.

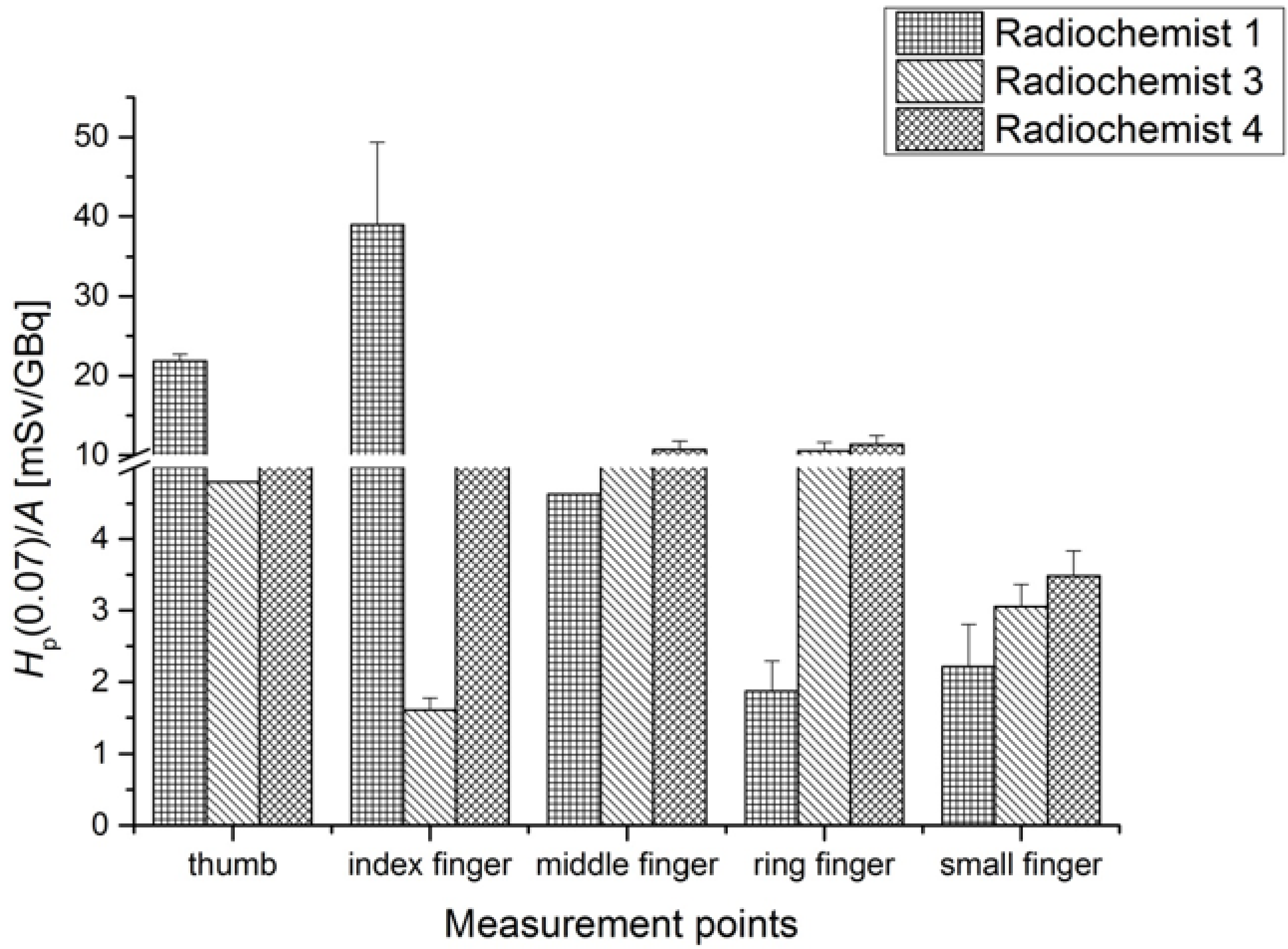

Figure 5

Average values of $H_p(0.07)$/A (with standard error) recorded at all measurement points of the left hand for radiochemists dispensing the doses of ^{68}Ga-DOTA-TATE for the patients.

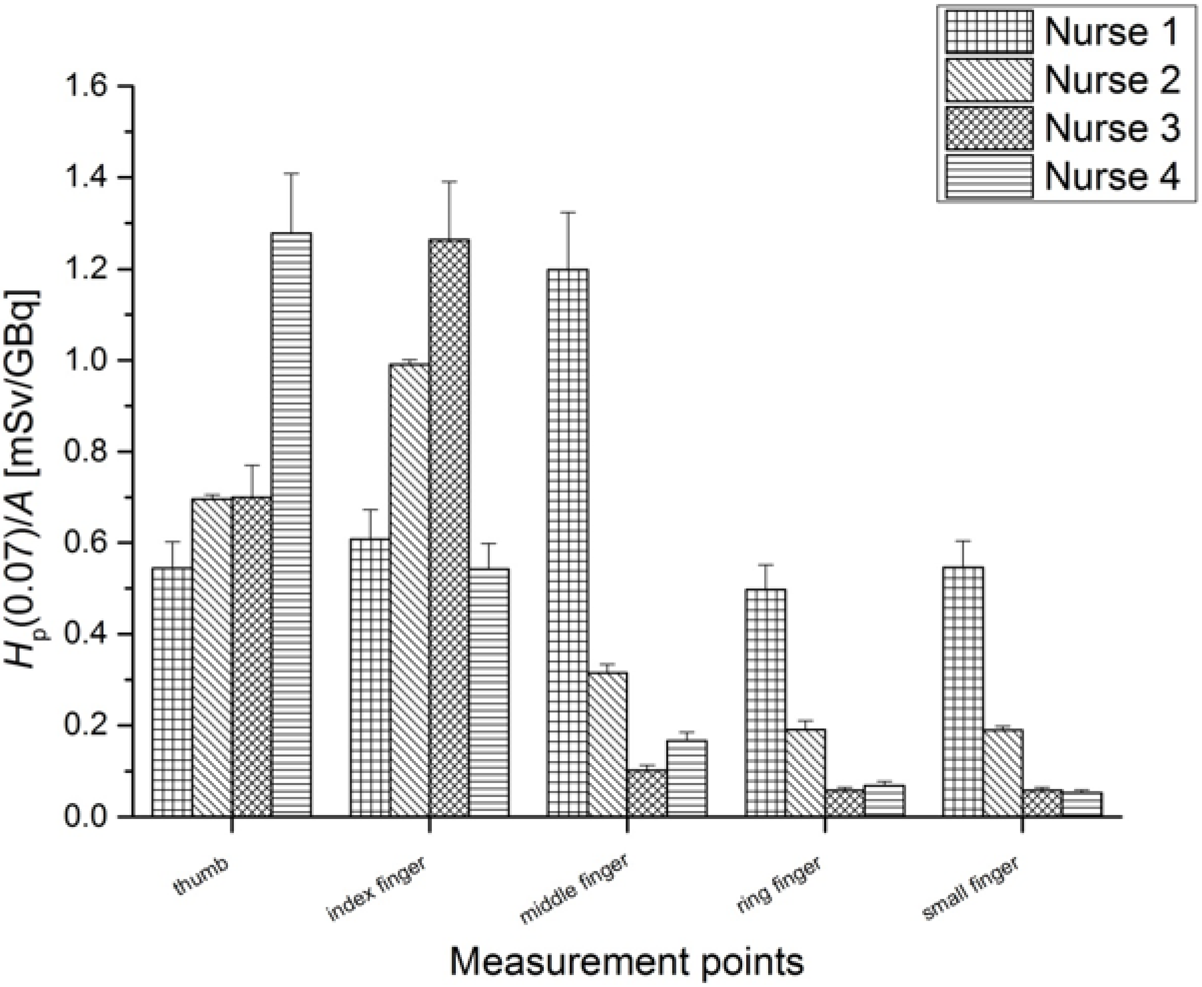

Figure 6

Average values of $H_p(0.07)/A$ (with standard error) recorded at all measurement points (of the left hand) for nurses during the injection of ^{68}Ga-DOTA-TATE for the patients.

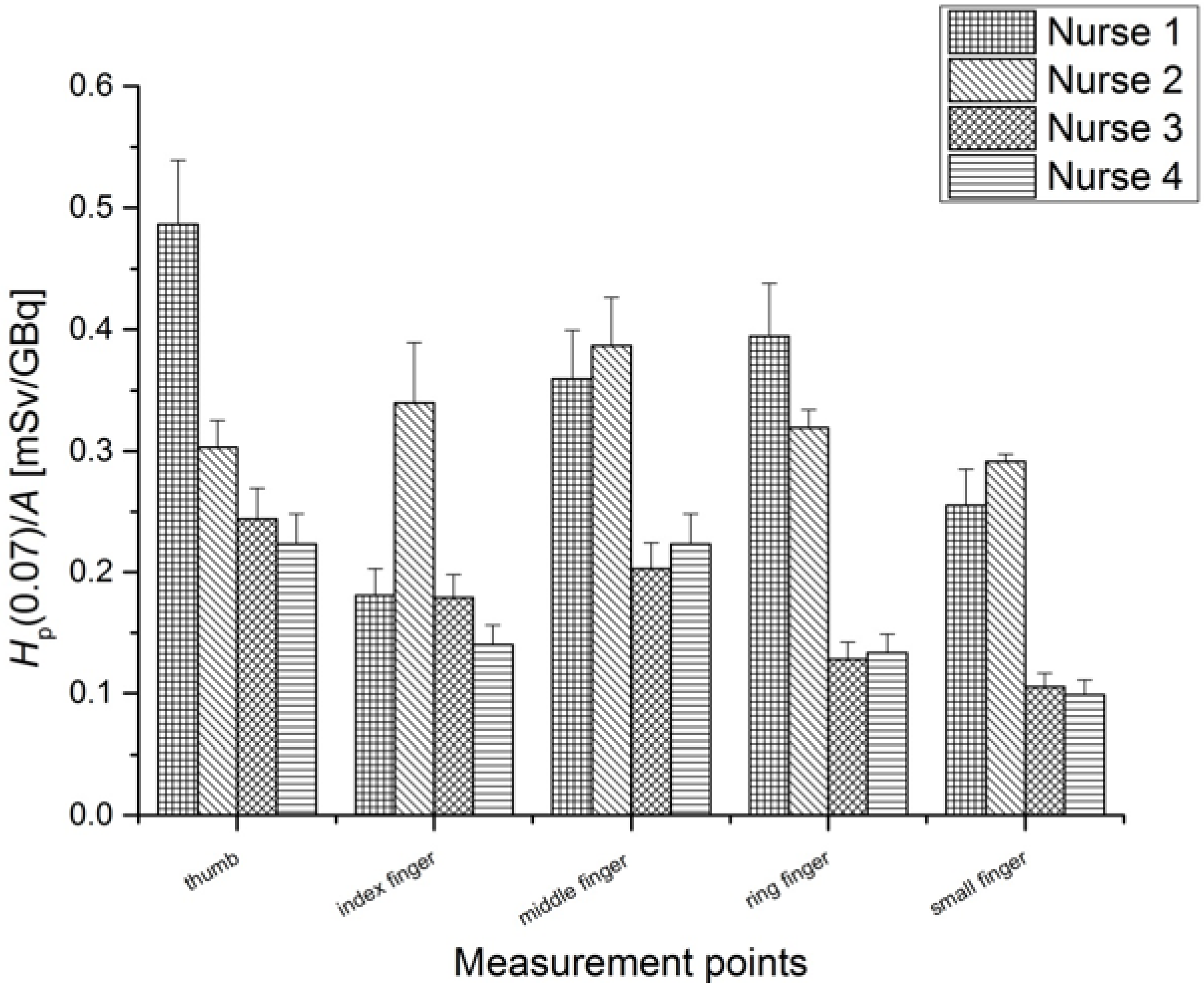

Figure 7

Average values of $H_p(0.07)/A$ (with standard error) recorded at all measurement points (of the right hand) for nurses during the injection of ^{68}Ga-DOTA-TATE for the patients.

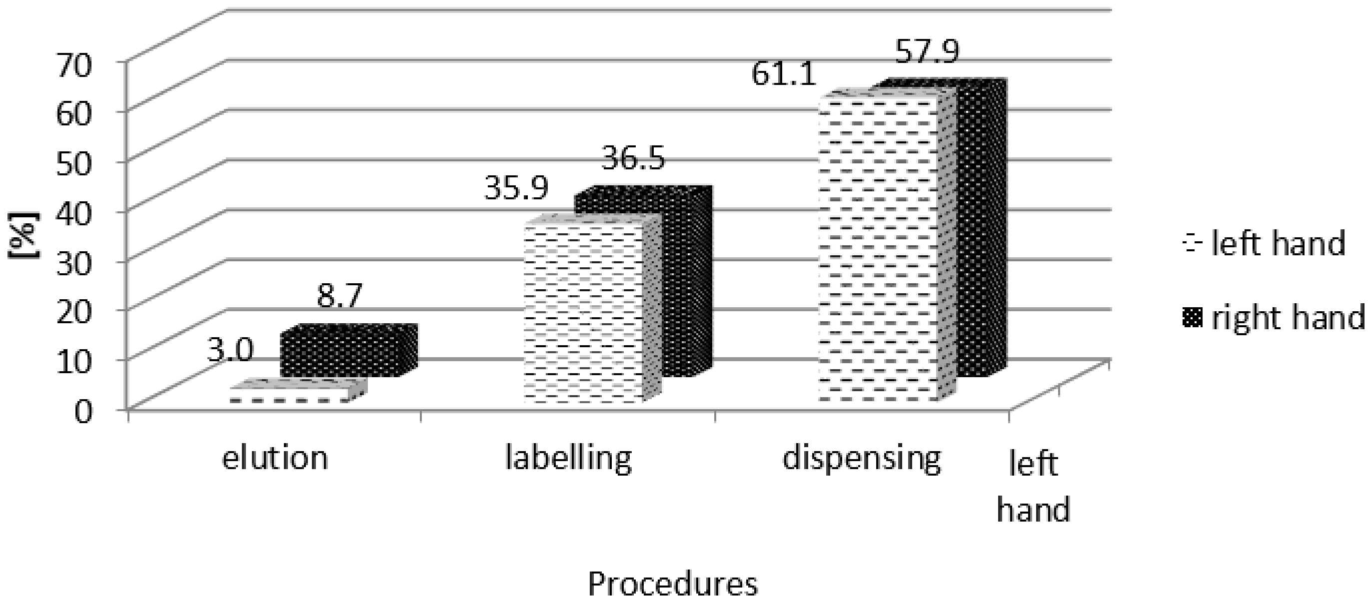

Figure 8

Percentage of activities in the total value of $H_p(0.07)$ obtained during the preparation of ^{68}Ga-DOTA-TATE.

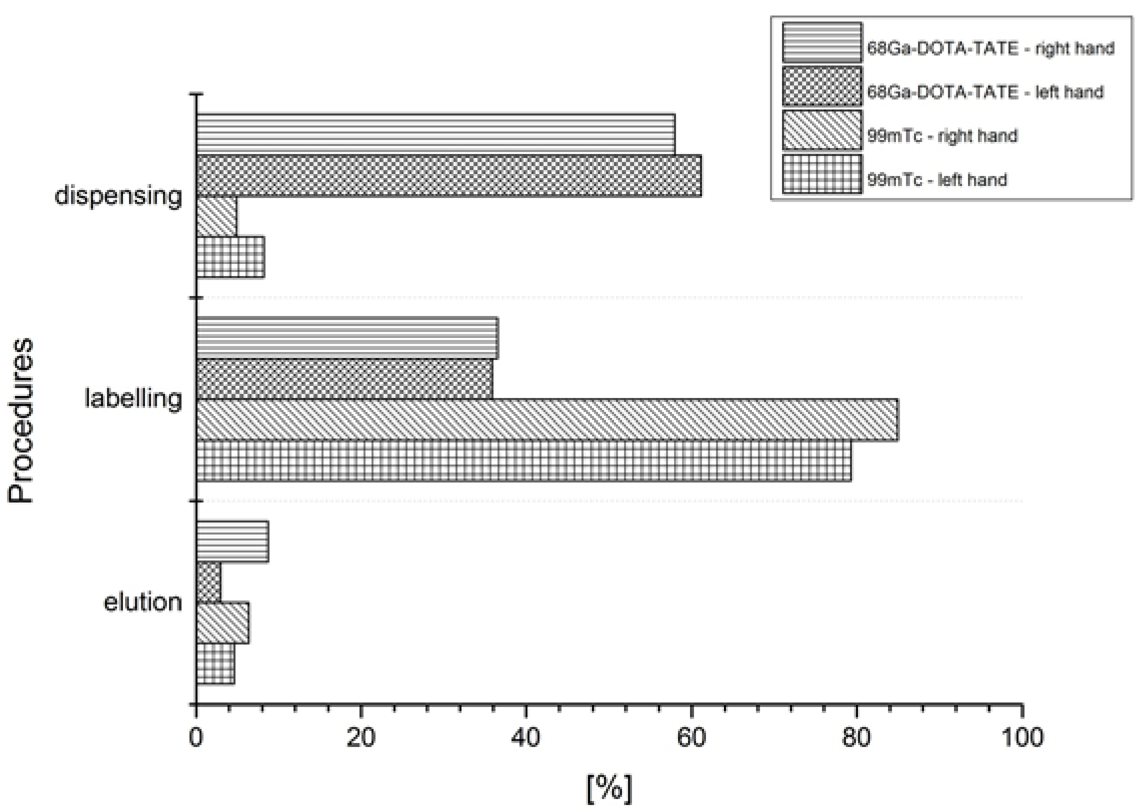

Figure 9

Percentage of the $H_p(0.07)/A$ value for each of the production procedures for the left and right hand of radiochemists responsible for the production of ^{68}Ga-DOTA-TATE and ^{99m}Tc.

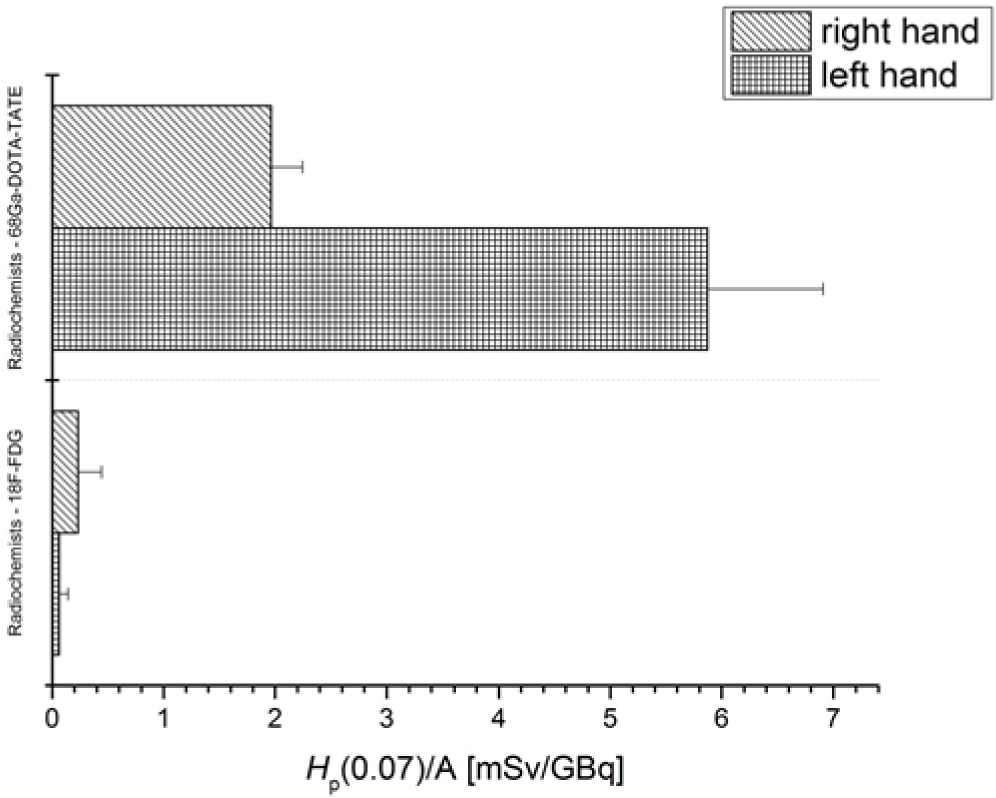

Figure 10

Average values of $H_p(0.07)/A$ (with standard error) recorded for Radiochemists during the dispensing the ^{68}Ga-DOTA-TATE and ^{18}F-FDG dose to the patients.

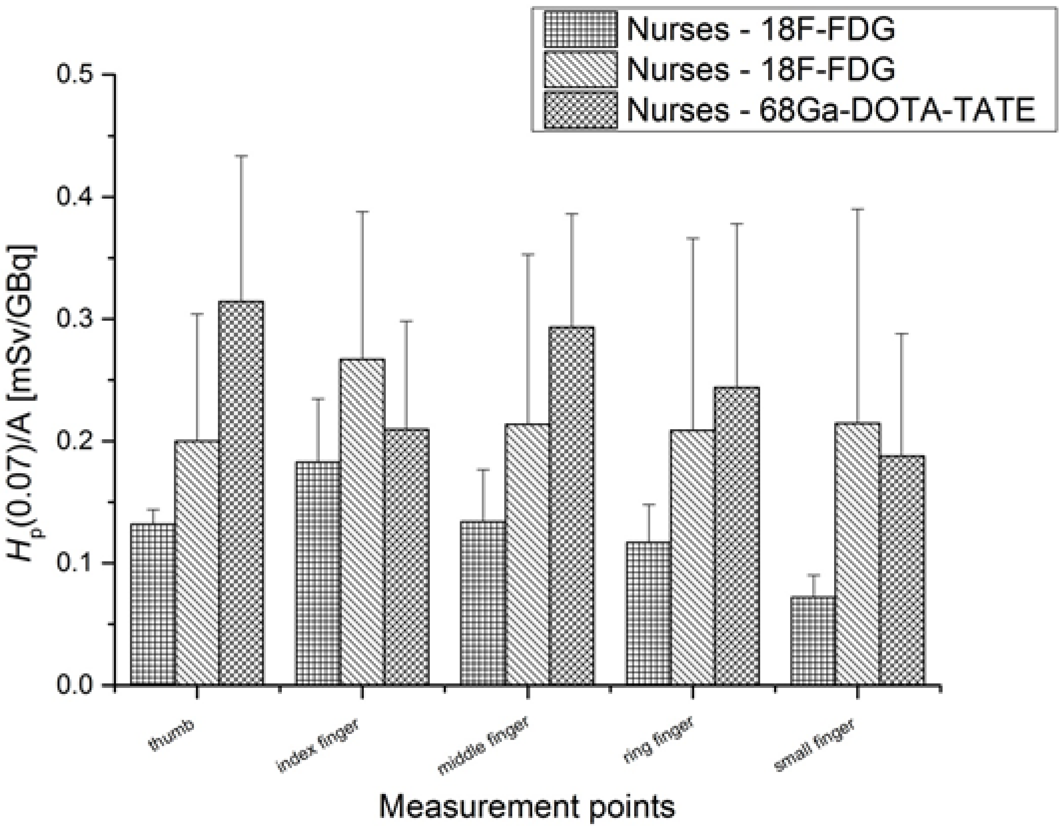

Figure 11

Average values of $H_p(0.07)/A$ (with standard error) recorded for the right hand of nurses during the injection of ^{68}Ga-DOTA-TATE and ^{18}F-FDG for the patients.

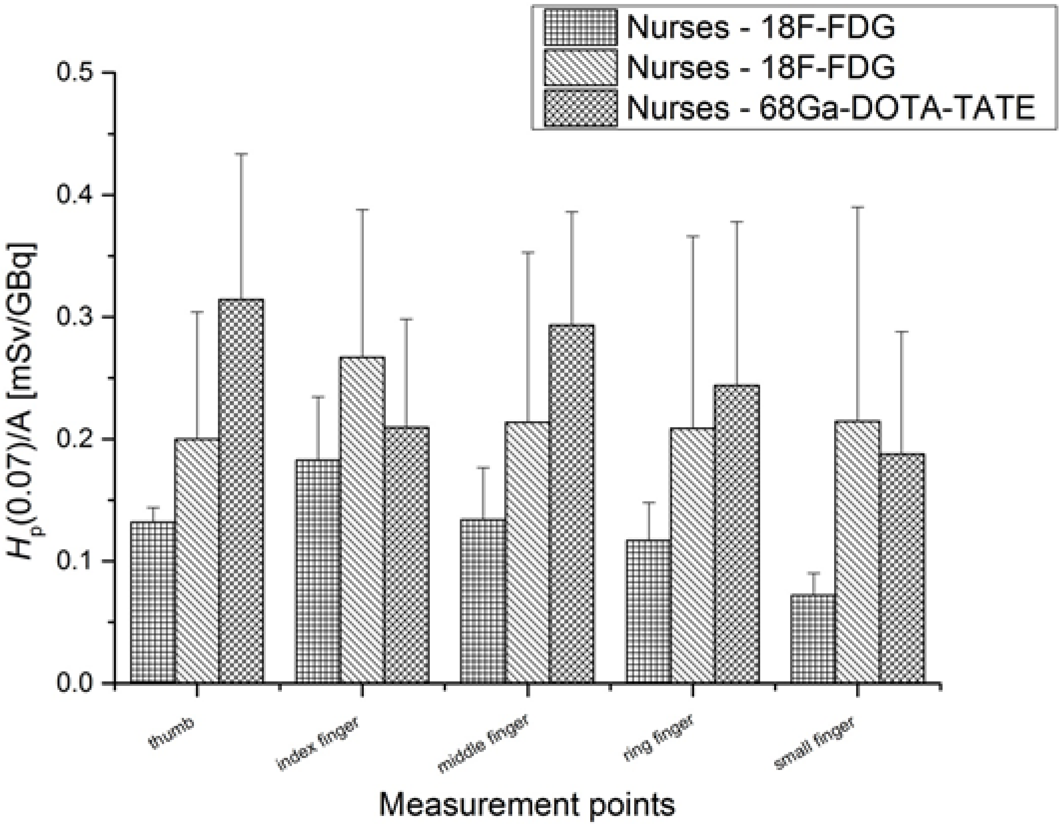

Figure 12

Average values of H_p(0.07)/A (with standard error) recorded for the left hand of nurses during the injection of ^{68}Ga-DOTA-TATE and ^{18}F-FDG for the patients.