Up-to-Date Quality Control and Radiation Protection in Nuclear Medicine

Summary of PhD Thesis

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1. Background

Regular quality control of the overall medical diagnostic procedure is indispensable when advanced technology is applied. In 1991, we introduced up-to-date quality control protocols for control of the in vivo and in vitro nuclear medicine instruments in the Nuclear Medicine Department of the University of Szeged. At that time, a Siemens Diacam-Icon SPECT camera was purchased, which was then the most modern instrument in Hungary. We also procured a dynamic line phantom and with this checked our gamma cameras and SPECT instruments. In 1994, the World Health Organisation (WHO) and the International Atomic Energy Agency (IAEA) organised an international interlaboratory study for the quality control of nuclear medicine bone studies, using a black box type, transmission bone phantom. Hungary participated in that study. Transmission bone phantom measurements were made in 22 Hungarian laboratories with the WHO/IAEA standard protocol, but we additionally performed complementary measurements, to investigate the performance parameters of the gamma cameras and imaging protocols in the participating laboratories, in order to obtain an overview of the performance of nuclear medicine bone imaging at a national level. The results were processed and the participants were informed individually about their performance and about the best, the worst and the mean national results. In 1994-1995, a FEFA grant was utilised at the University of Szeged to develop a digital Picture Archiving and Communication System (PACS). We investigated the performance of this system under controlled conditions, while phantom images were transmitted, archived and retrieved from the archive.

In 1997, our department joined the National Radiation Protection Alarm System (OSJR) of the Ministry of Education. With the financial support for the OSJR system, during recent years we have acquired two highly sensitive proportional counter tubes (which are also suitable for natural background measurements), a Geiger-Müller counter, a surface contamination monitor, and electronic personal

dosimeters. With these instruments, we have performed numerous measurements during our diagnostic and therapeutic investigations on patients.

2. Aims

The aims of my work were to obtain answers to the following questions:

- 1. Which gamma camera parameters can be investigated with the dynamic line phantom?
- 2. Under what conditions is the dynamic line phantom suitable for the quality control of gamma camera detector uniformity?
- 3. How are the transmission bone phantom images influenced by the type of the flood source?
- 4. What is the level of performance of Hungarian nuclear medicine laboratories in performing bone scintigraphy?
- 5. What is the level of performance of the PACS system developed at the University of Szeged in the handling of medical images? Is there any loss of information during picture archiving and picture transmission?
- 6. During lung ventilation studies, how much radioaerosol escapes into the atmosphere of the patient investigation room, and how much impact does this have on the background dose level? What is the whole-body dose of the technician performing lung ventilation studies and which are the critical organs for the incorporated radiopharmaceutical?
- 7. How high are the whole-body and finger doses of the surgical personnel due to radiolabelled sentinel node (SLN) localisation and excision in the surgical intervention of malignant melanoma (MM)?

3. Methods

For quality control measurements, we have used phantoms (dynamic line, transmission bone, SPECT total performance, liver, thyroid, CT, ultrasound, breast, and DSA software phantoms). The phantom images were interpreted visually and/or quantitatively, and by means of the receiver operating characteristic (ROC) curves.

For radiation protection measurements, we have used an intraoperative gamma probe, proportional counter tube, and electronic and thermoluminescent personal dosimeters.

3.1. Quality control of the gamma camera detectors using a dynamic line phantom

With the dynamic line phantom (a microprocessor-controlled capillary tube fillable with radioactive solution) we effectuated test images on two MB9200 (Picker Dyna 4C/15 licence) gamma cameras and on a Siemens Diacam-Icon SPECT device. For determination of the detector uniformity, linearity, geometrical resolution, field of view size and line spread function, we have used the specific programs of the phantom: uniformity determination, PLES (parallel lines equally spaced), hot-line and cold-line resolution, MTF (modulation transfer function), BRH (Bureau of Radiological Health), OHTP (orthogonal hole test pattern), dynamic range and Hine Duley. The test images were interpreted visually or quantitatively.

3.2. Investigation of the gamma camera detector uniformity using a dynamic line phantom

On four round and one square-shaped gamma camera detector, we determined count rate-activity and uniformity-count rate characteristics, with and without a collimator, using a dynamic line phantom. The uniformity values were compared with values obtained by using a ^{99m}Tc point source or a ⁵⁷Co sheet source, respectively.

3.3. Comparison of the quality of bone phantom images obtained with different radiation sources

Transmission bone phantom images were obtained with three MB9200 gamma cameras, one Siemens Diacam and one Elscint Helix SPECT device, using a fillable flood source, a ⁵⁷Co sheet source and a dynamic line phantom, respectively. The images were interpreted by three experienced observers with a score method, on a scale of 1-4. From the data, we calculated the ROC curves and compared the results obtained with the different radiation sources.

3.4. Interlaboratory comparison study with the WHO/IAEA transmission bone phantom in Hungary

On 28 gamma cameras and SPECT instruments in 22 Hungarian laboratories, we obtained WHO/IAEA transmission bone phantom images and performed quality control measurements, using the standard international interlaboratory study and our own protocol, respectively. The participants were asked to report about the hot and cold lesions of the phantom images, and rank the evidence of the lesion on a scale of 1-4. The observers' performance was characterised by the value of the area under the ROC curve.

3.5. Quality control of medical image transfer via computer network

Phantom images suitable for quality control purposes were obtained on SPECT, CT, ultrasound, MRI, DSA and mammography devices. The phantom images were documented on X-ray films and visually interpreted by three experienced observers with scoreing on a scale of 1-4. The digital images from the modalities linked to the PACS system were sent directly via the network to the image server; in the other cases, the X-ray images were redigitalised by using a film scanner and then sent to the server. The phantom images on the central display were interpreted by the same three observers, using the same method as for the interpretation of the primary X-ray images. In the case of the bone phantom, both the digital and redigitalised

images were sent via the network, and in this way the observers were able to interpret the images in all three editing modes (1. X-ray film, 2. digital image sent via the network, 3. image redigitalised, and then sent via the network). The observers were asked to report on the questions in connection with the structure of the phantom images.

3.6. Radiation safety considerations in ^{99m}Tc-DTPA radioaerosol lung ventilation studies

We investigated the increase in the background radiation level and the radioaerosol activity concentration in the patient investigation room where the aerosol production equipment was

functioning, following 1-6 ventilation studies/day. On the technicians performing the patient studies, we performed whole- body investigations with a SPECT camera without a collimator in place, and static studies with a collimator, to check on the possibility of incorporated radioaerosol. We estimated the effective whole-body doses of the technicians. The radioactive contamination of the technicians' gloves, and the floor and the walls of the investigation room was checked with a smear test.

3.7. Sentinel lymph node detection in malignant melanoma patients: radiation safety considerations

Radiation protection measurements were performed in connection with surgical interventions on 25 MM patients (18 females, 7 males) who underwent SLN localization by means of a radioisotope technique. The variation in the background doses was investigated by using a proportional counter tube, the personnel doses were determined with electronic personal dosimeters, and the extremity doses of the surgeon and assistant surgeon were measured with LiF thermoluminescent ring dosimeters.

4. Results

4.1. Quality control of the gamma camera detectors using a dynamic line phantom

The uniformity of the gamma camera detectors was investigated with and without a collimator. The uniformity could be checked visually on all of the dynamic line phantom images. Systematic artefacts (stripes or patches) due to a possible phantom defect were not observed. The linearity of the detector with a collimator was investigated with the PLES, BRH and OHTP test programs. The geometrical resolution was checked appropriately with MTF and resolution hot-lines tests. The dynamic range and Hine Duley programs were not considered suitable for quality control purposes. On use of the OHTP phantom test program, with a medium-energy diverging collimator, a Moiré effect was observed.

4.2. Investigation of the gamma camera detector uniformity using a dynamic line phantom

From the count rate measurements with the capillary tube of the dynamic line phantom on the count rate-activity characteristics of the same type of gamma cameras, the limit of the linear relationship was found to be ~ 30 000 cps, the 20% dead time losses occurred at ~ 50 000 cps and the maximum count rate was found to be 70 000 cps. On the investigated gamma cameras a well-defined count rate interval was found which provided stable uniformity values of the detector, which did not differ significantly (p<0.05) from those obtained with a ^{99m}Tc point source or a ⁵⁷Co sheet source.

4.3. Comparison of the quality of bone phantom images obtained with different radiation sources

The mean values of the areas under the ROC curves, obtained from the bone phantom images produced with the three different radiation sources (^{99m}Tc flood

source vs. line phantom: $0.86 \pm 0.04/0.86 \pm 0.03$; ^{99m}Tc flood source vs.⁵⁷Co sheet source: $0.87 \pm 0.04/0.88 \pm 0.04$; line phantom vs. ⁵⁷Co sheet source: $0.88 \pm 0.03/0.87 \pm 0.04$) did not differ significantly (p<0.02).

4.4. Interlaboratory comparison study with the WHO/IAEA transmission bone phantom in Hungary

In the interlaboratory quality control study performed in Hungarian laboratories, the performances of the participants, characterised by the value of the area under the ROC curves, displayed quite large differences; the worst results did not differ greatly from the value of 0.5 (the national lowest value: 0.60) which would be obtained by an observer giving score values purely by chance, but at the same time the best values were around 1; the maximum possible value (the national highest value: 0.94). The results obtained from interpretation of the analogue and digital images were compared separately, and the difference was found to be significant (p<0.01) in favour of the display (0.85 ± 0.01 vs. 0.76 ± 0.04). The integral and differential uniformity values of the detectors in both fields of view were spread over large intervals: 3-8% and 2.4-3.8%, respectively.

4.5. Quality control of medical image transfer via computer network

The scores of the X-ray films and the digital images transmitted via the network (total: 303) were identical in 234 (77%) cases. Higher scores were obtained from the X-ray film in 43 cases (14%) and from the display in 26 cases (9%). For the X-ray film and the redigitalised images transmitted via the network, a total of 132 scores were analysed. 63 (48%) were identical, while 51 (39%) were more precise from the X-ray film, and 18 (13%) were more precise from the display. As concerns the transmission bone phantom images, the highest ROC curve areas were obtained from the digital images (0.937 \pm 0.03), followed by the primary X-ray images (0.934 \pm 0.20). The weakest result was obtained from the images

redigitalised with a film scanner and transmitted via the network (0.931 \pm 0.02). The differences were not significant.

4.6. Radiation safety considerations in ^{99m}Tc-DTPA radioaerosol lung ventilation studies

In the surroundings of the aerosol-producing equipment, the background dose values were found to lie in a large interval, but increased significantly (p=0.05) with increase in the number of lung ventilation patient studies. The estimated effective dose of the technician from the external radiation source was < 200 nSv in 74% of the investigations (121 patient study), and 200-850 nSv in 26% (44 patient study). The radioaerosol activity concentration varied in the interval 5-141 kBq/m³. The effective internal doses of the technician estimated with the lowest and with the highest radioaerosol concentrations were 0.6 nSv and 0.3 μ Sv, respectively. On the whole-body images, adiopharmaceutical incorporation was detected in the oral cavity, and less frequently in the stomach. The gloves used by the technicians showed contamination in the range 88–171 Bq; no contamination was detected on the floor or on the walls of the investigation room.

4.7. Sentinel lymph node detection in malignant melanoma patients: radiation safety considerations

The mean background dose rate level in the surgery did not differ from that at other sites in the building: 92.5 ± 2.2 nSv/h (mean \pm SD).

In 21 cases (24%) the measured doses were < 1 microSv, but in 4 operations (16%) 1-4.5 microSv was received. The equivalent dose rate was generally < 1 microSv/h. The finger-absorbed doses for the surgeon and the assistant surgeon were (mean \pm SD) 159 \pm 23 microGy and 48 \pm 17 microGy per intervention, respectively. The detected counts for the SLNs varied in a large interval; the mean (\pm SD) (n=36) was 11756 \pm 7858 counts/10 s. The counts detected at the sites from which the SLNs

were removed (n=36) varied between 0.03% and 10% (median 2.6%) of the counts for the SLNs.

5. Conclusions

- 1. The dynamic line phantom is suitable for investigations of the uniformity, linearity and geometrical resolution of gamma camera detectors with a collimator in place and for uniformity checks on detectors without a collimator.
- 2. The dynamic line phantom is suitable for the determination of the uniformity of round and square-shaped detectors, but the measurements should be performed within a well-defined activity (count rate) interval.
- 3. Transmission bone phantom images can be appropriately obtained by using a dynamic line phantom as a flood source.
- 4. The serial WHO/IAEA transmission bone phantom measurements in Hungarian laboratories revealed that the performance of the participants varies in a broad range, and this type of quality control procedure provides valuable information in support of the improvement of the individual effectiveness. The results demonstrated that the optimum setting of the gamma cameras (with special regard to the uniformity) and the careful professional image interpretation (from the hardcopy and display together) are the most important parameters influencing the quality of bone scintigraphy investigations.
- 5. The quality control of the PACS system, with our simple method, using phantom image transfer via the network, is suitable for the detection of possible errors in the system.
- 6. The technicians performing patient lung ventilation studies with radioaerosol are additionally exposed to internal doses, the radiopharmaceutical ^{99m}Tc-DTPA mainly being absorbed in the oral cavity and in the stomach. The effective doses received by these technicians from the external and internal sources remain below the limits set by the regulations.

7. In surgical interventions on MM the localisation and excision of the SLN by using the radioisotope technique can be performed safely from a radiation protection point of view. Personal dosimetric survey and limitation of the number of surgical interventions do not appear to be essential.

6. List of the author's scientific publications related to the subject of the PhD thesis

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