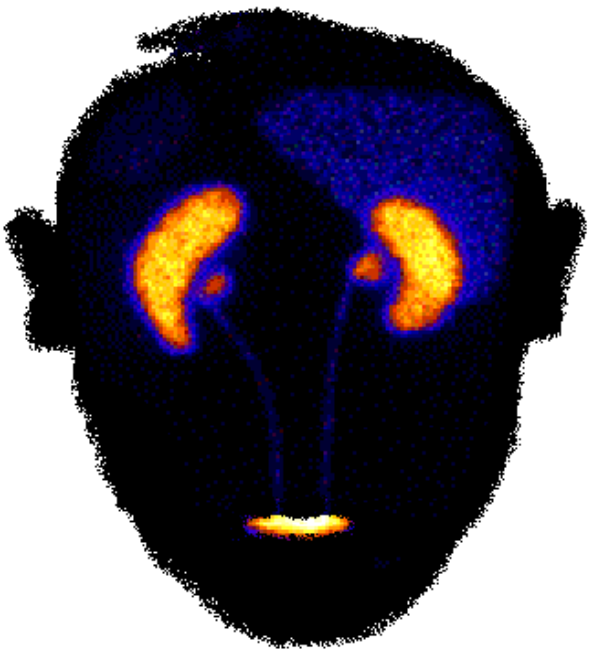
Kuopion yliopiston julkaisuja C. Luonnontieteet ja ympäristötieteet 89
Kuopio University Publications C. Natural and Environmental Sciences 89

Jari O. Heikkinen

EXTERNAL QUALITY ASSURANCE OF NUCLEAR MEDICINE IMAGING



KUOPIO 1999

Kuopion yliopiston julkaisuja C. Luonnontieteet ja ympäristötieteet 89
Kuopio University Publications C. Natural and Environmental Sciences 89

Jari O. Heikkinen

EXTERNAL QUALITY ASSURANCE OF NUCLEAR MEDICINE IMAGING

Doctoral dissertation

To be presented by permission of the Faculty of Natural and Environmental Sciences of the University of Kuopio for public examination in Auditorium L3, Canthia building, University of Kuopio, on Friday 23rd April 1999, at 12 noon

Department of Clinical Physiology and Nuclear Medicine
Kuopio University Hospital and
Department of Applied Physics
University of Kuopio

Kuopio 1999

Distributor:
Kuopion University Library
P.O.Box 1627
FIN-70211 KUOPIO
FINLAND
Tel. +358 17 163 430
Fax +358 17 163 410

Series editor:
Lauri Kärenlampi, Ph.D., Professor
University of Kuopio

Author's address:
Etelä-Savo Hospital District
Mikkeli Central Hospital
Porrassalmenkatu 35-37
FIN-50100 MIKKELI
FINLAND
Tel. +358 351 2452
Mobile Phone +358 40 543 2169
Fax +358 15 351 2406 or +358 15 351 2750
E-mail: jari.heikkinen@esshp.fi

Supervisors:
Docent Jyrki T. Kuikka, Ph.D.
Department of Clinical Physiology and Nuclear Medicine
Kuopio University Hospital

Docent Aapo Ahonen, M.D.
Department of Nuclear Medicine
Oulu University Hospital

Reviewers:
Professor emeritus Ahti Rekonen, Ph.D.
Department of Physics
University of Jyväskylä

Docent Martti Hannelin, Ph.D.
Department of Clinical Physiology
South-Karelia Central Hospital
Lappeenranta

Opponent:
Docent Matti Koskinen, Ph.D.
Department of Physiology
Tampere University Hospital

ISBN 951-781-727-4
ISSN 1235-0486

Kuopio University Printing Office
Kuopio 1999
Finland

Heikkinen, Jari O. External quality assurance of nuclear medicine imaging. Kuopio University Publications C. Natural and Environmental Sciences 89. 1999. 50 p.
ISBN 951-781-727-4
ISSN 1235-0486

ABSTRACT

The quality of nuclear medicine imaging, as in all imaging modalities, depends on the whole investigation procedure. If any of the separate steps is unsatisfactory, the result is not reliable. Most of the individual steps and the facility can, and should, be checked by employees of departments regularly, but this is not enough. The need for overall quality assurance by independent outside observers is taking place in medical imaging. In this work, methods and a phantom were developed for the external quality assurance of nuclear medicine imaging.

The pilot test was made in 1993 when bone imaging and brain perfusion single photon emission tomography (SPET) were evaluated in 19 Finnish laboratories. Since then Labquality Ltd. (Helsinki) has organised four external quality assurance tests of nuclear medicine in Finland. In 1994 eleven laboratories were studied with a bone phantom. A 3-D brain perfusion SPET phantom was imaged in twelve laboratories in 1995. The following year the quality of myocardial perfusion SPET imaging between 19 Finnish laboratories was compared with a cardiac phantom. Nineteen laboratories participated in the evaluation of dynamic radionuclide renography in 1997. A renal phantom was developed for that survey.

The results of the pilot test showed the need for objective audit tests of nuclear medicine imaging in Finland. In the first test by Labquality in 1994 one laboratory failed to detect any of the six spinal bone lesions. The quality of brain SPET images was good in only four out of twelve laboratories in 1995. Quality was amazingly low with the others. Laboratories used a wide scale of methods in myocardial perfusion SPET imaging and, sometimes, inappropriate protocols. Results of the renography test suggest that the difference between laboratories is most probably due to variations in protocols and programs.

The present study shows that the quality of nuclear medicine imaging in Finland is heterogeneous. The laboratories producing the best and the worst quality varied between the surveys. The reasons are most probably the difficulty of nuclear medicine, the varying interest towards examinations and the lack of resources to concentrate enough on all procedures. Also, the lack of standardisation and harmonisation of investigations play major role. The methods and the developed renal phantom described in this study were found suitable for multicentre evaluation of overall quality in nuclear medicine. The quality of medical imaging has to be high to ensure total patient care. Regular external quality assurance by independent observer is one implement of overall quality management of nuclear medicine. These results and findings shall promote other countries and fields of medicine to perform regular external quality assurance surveys, too.

National Library of Medicine Classification: W 84, WN 180, WN 203, WN 206
Medical Subject Headings: diagnostic imaging; nuclear medicine; tomography, emission-computed, single-photon; radioisotope renography; phantoms, imaging; laboratories; quality control; bone and bones; brain; heart; kidney

Heikkinen, Jari O. Isotooppikuvantamisen ulkoinen laaduntarkkailu. Kuopion yliopiston julkaisuja C. Luonnontieteet ja ympäristötieteet 89. 1999. 50 s.
ISBN 951-781-727-4
ISSN 1235-0486

TIIVISTELMÄ

Isotooppikuvantamisen, kuten kaikkien muidenkin kuvantamismenetelmien, laatuun vaikuttaa koko tutkimusketju. Jos yksikin vaihe epäonnistuu ei lopputulos ole luotettava. Tutkimuksia tekevän laboratorion henkilökunta voi ja heidän täytyy varmistaa useimpien erillisten vaiheiden sekä laitteiden laatu säännöllisesti, mutta se ei yksin riitä. Koko tutkimusketjun laadun varmistus ulkopuolisen tarkkailijan toimesta on alkanut saada sijaa lääketieteellisessä kuvantamisessa. Tässä työssä on kehitetty menetelmiä ja testikohde isotooppikuvantamisen ulkoiseen laaduntarkkailuun.

Pilottitesti tehtiin vuonna 1993, jolloin selvitettiin luuston gammakuvauksen ja aivoperfuusion yksifotoniemissiotomografian (SPET) tilanne 19 suomalaisessa isotooppilaboratoriossa. Sen jälkeen Labquality Oy (Helsinki) on organisoinut neljä ulkoista laaduntarkkailukierrosta Suomessa. Vuonna 1994 tutkittiin 11 laboratorion luuston gammakuvausta. Kolmedimensionaalinen aivotestikohde kuvattiin 12 laboratoriossa vuonna 1995. Seuraavana vuonna sydänlihaksen perfuusion SPET-kuvausta selvitettiin 19 laboratoriossa sydäntestikohteella. Munuaistoiminnan gammakuvauksen laaduntarkkailukierrokseen osallistui myös 19 laboratoriota vuonna 1997. Tuota kierrosta varten kehitettiin dynaaminen munuaistestikohde.

Pilottikierroksen tulokset osoittivat ulkoisten laaduntarkkailukierrosten tarpeellisuuden Suomessa. Labqualityn organisoimassa testissä vuonna 1994 yksi laboratorio ei havainnut yhtään kuudesta selkärangan muutoksesta. Aivojen SPET-kuvien laatu oli hyvä ainoastaan neljässä laboratoriossa vuonna 1995. Laatu oli yllättävän huono muilla osallistujilla. Sydänlihaksen perfuusion SPET-kuvauksessa käytettiin menetelmiä, joista kaikki eivät olleet hyväksyttäviä. Vaihtelut munuaistoiminnan gammakuvauksen tuloksissa johtuvat todennäköisesti eroista kuvausprotokollissa ja analyysiohjelmissa.

Tutkimus osoitti, että isotooppikuvantamisen laatu on heterogeenistä Suomessa. Jokaisella kierroksella parhaan ja huonoimman tuloksen saaneet laboratoriot vaihtelivat. Syitä ovat todennäköisesti isotooppilääketieteen vaativuus, vaihteleva mielenkiinto tutkimuksia kohtaan ja voimavarojen puute, jotta kaikkiin tutkimuksiin voitaisiin panostaa riittävästi. Myös tutkimusten standardisoinnissa ja yhtenäistämisessä on puutteita. Tässä työssä kehitetyt menetelmät ja munuaistestikohde todettiin sopiviksi isotooppikuvantamisen ulkoiseen laaduntarkkailuun. Potilaan hyvä hoito edellyttää korkealaatuista lääketieteellistä kuvantamista. Riippumattoman tarkkailijan tekemä säännöllinen ulkoinen laaduntarkkailu on yksi osa isotooppilääketieteen kokonaislaadun hallintaa. Näiden tulosten ja havaintojen toivotaan kannustavan myös muita maita ja lääketieteen erikoisaloja tekemään säännöllisiä ulkoisia laaduntarkkailukierroksia.

National Library of Medicine Classification: W 84, WN 180, WN 203, WN 206
Medical Subject Headings: diagnostic imaging; nuclear medicine; tomography, emission-computed, single-photon; radioisotope renography; phantoms, imaging; laboratories; quality control; bone and bones; brain; heart; kidney

To Hanna, my mother, and Voitto, my father

ACKNOWLEDGEMENTS

This work was carried out in the Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital, and in the Department of Nuclear medicine, Mikkeli Central Hospital, during the years 1993-1998. Measurements were made also in the following hospitals: University Hospital of Helsinki, Kuopio, Oulu, Tampere and Turku and Central Hospital of Helsinki (Aurora, Laakso, Malmi and Maria), Hämeenlinna, Joensuu, Jyväskylä, Kajaani, Karjaa, Kemi, Kokkola, Kotka, Lahti, Lappeenranta, Mikkeli, Pori, Seinäjoki, Savonlinna, Rovaniemi and Vaasa. Several persons have contributed to my thesis. I owe my sincere thanks to

- my supervisors
- my principal supervisor Docent Jyrki T. Kuikka, Ph.D., for his continuous patience and guidance during my research and during my career
- Docent Aapo Ahonen, M.D., for his guidance, criticism and profitable discussions

- my official reviewers
- Professor Ahti Rekonen, Ph.D. and
- Docent Martti Hannelin, Ph.D. for their critical review of the manuscript and valuable suggestions for its improvement

- co-authors and specialists
- Pentti Rautio, Lic.Med., for his constructive criticism and collaboration
- Docent Jukka Jurvelin, Ph.D., Kauko Hartikainen, M.Sc., and Gösta Kvist, M.D. (†) for their contribution to the pilot survey
- Docent Tuomo Lantto, M.D. and Docent Esko Vanninen, M.D., for their collaboration in evaluating reports

- the personnel of each department of the participating hospitals
- especially Esa Ahonen, Atso Arstila, Martti Hannelin, Kauko Hartikainen, Jorma Heikkonen, Aimo Hietanen, Håkan Jungar, Matti Karhunen, Helena Kiiliäinen, Anneli Korolainen, Tapani Korppi-Tommola, Matti Koskinen, Tomi Laitinen, Martti Larikka, Kimmo Leinonen, Riitta Mattinen, Petri Mikkola, Hanna Mussalo, Martti Männikkö, Päivi Nikkinen, Sakari Parviainen, Keijo Saali, Inkeri Sippo-Tujunen, Mirja Tenhunen-Eskelinen, Jarmo Toivanen, Pentti Torniainen, Virpi Tunninen, Voitto Tuomainen, Esko Vanninen, Seppo Verho, Jari Viitanen, Antti Virjo and Juha Vuorela for their valuable collaboration

I am grateful to

- all persons and institutions who made my research possible
- Professor Esko Länsimies, M.D., and the personnel of the Department of Clinical Physiology and Nuclear Medicine in University Hospital of Kuopio for providing facilities for research and their technical assistance and help during this work
- my co-workers Sinikka Valanta and Matti Airaksinen for their help, support and for sharing their experience with me during this work - it has been a great privilege to work with them in stimulating atmosphere
- the personnel of the Department of Clinical Laboratory and the Department of Radiology of Mikkeli Central Hospital for their help, support and encouragement during the study
- Minna Loikkanen, M.Sc. and the personnel of Labquality Ltd., for their co-operation
- The Association of Finnish Local Authorities for support
- the personnel of the Department of Technics in Mikkeli Central Hospital,

especially to Markku Rantalainen and Kari Hokkanen who made the most parts of the renal phantom
- Asko Leinonen and Tomi Kauppinen, Lic.Sc., for sharing their experience and help with the test of the renal phantom
- Leo Tarssanen, M.D., Chief Physician, Department of Medicine, Medical Director, the physicians in the Department of Internal Medicine and the personnel of Mikkeli Central Hospital for their friendly encouragement and help during the study
- Jukka Männistö, L.L.M, Director of Hospital District, Pekka Ruohonen, Lic.Med., M.Sc., Medical Director, and the personnel of Etelä-Savo Hospital District for their support and encouragement
- Professor Jari Kaipio, Ph.D., and the personnel of the Department of Applied Physics and University of Kuopio, for their help
- Docent Erkki Vauramo, Ph.D., for his valuable help
- University Hospital of Kuopio, for the research post
- Tuomas Ahonen, for helping with the language check
- Keijo Korhonen, M.Sc., and Nycomed Amersham Finland, for his help and support

I want to thank all my friends for their encouragement and support during these years.

Finally, my warmest thanks to my family for their support and encouragement. I dedicate this work to Hanna, my mother, and Voitto, my father. Their care and discipline made this work possible.

Mikkeli, April 1999

Jari Heikkinen

ABBREVIATIONS AND SYMBOLS

3-D = three dimensional
ACEI = angiotensin-converting enzyme inhibitor
ACNP = American College of Nuclear Physicians
AV-block = atrio ventricular block
BBB = blood-brain barrier
COST B2 = Co-operation in Science and Technology, B2, of the European Union
CT = computed tomography
DTPA = diethylenetriaminepentaacetic acid
EANM = European Association of Nuclear Medicine
ECD = ethyl cysteinate dimer (bicisate)
ECG = electrocardiography
EEG = electroencephalography
F+0 = furosemine injection at the same time as the injection of the radiopharmaceutical
F+20 = furosemine injection 20 minutes after the injection of the radiopharmaceutical
F-15 = furosemine injection 15 minutes before the injection of the radiopharmaceutical
HMPAO = hexamethyl propyleneamine oxime
IAEA = International Atomic Energy Agency
i.v. = intravenous
MAG3 = mercaptoacetyltriglycine
MRI = magnetic resonance imaging
MTT = mean transit time
NEMA = National Electronic Manufacturers' Association
p.o. = per os
PSA = prostate specific antigen
QA = quality assurance
ROI = region of interest
SD = standard deviation
SPET = single photon emission tomography
SPECT = single photon emission computed tomography
STUK = Säteilyturvakeskus = Finnish Centre for Radiation and Nuclear Safety
$T_{½}$ = physical half-life
T_{max} = time to reach maximum activity
WHO = World Health Organization

*Cover picture: Modified image of a simulation of dynamic radionuclide renography with the new renal phantom.

LIST OF THE ORIGINAL PUBLICATIONS

This thesis is based on the articles referred to in the text by their Roman numerals:

I Heikkinen J, Kuikka JT, Ahonen A, Jurvelin J, Hartikainen K and Kvist G: A Finnish multicentre quality assurance project in bone scintigraphy and brain SPET: a phantom study. Nucl Med Commun 15:795-805, 1994

II Heikkinen J, Kuikka JT, Ahonen A and Rautio P: Quality of brain perfusion single-photon emission tomography images: multicentre evaluation using an anatomically accurate three-dimensional phantom. Eur J Nucl Med 25:1415-1422, 1998

III Heikkinen J, Ahonen A, Kuikka JT and Rautio P: Quality of myocardial perfusion SPET imaging: multicentre evaluation with a cardiac phantom. (submitted)

IV Heikkinen J: A dynamic phantom for radionuclide renography. Phys Med Biol 44:39-53, 1999.

1. INTRODUCTION

The basic principle of diagnostic nuclear medicine is the use of pharmaceuticals capable of carrying radionuclides that emit penetrating radiation. First the radionuclide and the pharmaceutical are combined, then the compound is injected into the circulatory system of the patient. The distribution of the radiopharmaceutical within the body can then be detected using gamma camera to image and quantify regional physiological biochemical processes. Single photon scintillation cameras (gamma camera) provide static, dynamic or gated images and single photon emission tomography (SPET, also known as SPECT) provides tomographic images by reconstruction of a number of planar images taken at regularly spaced angles. A diagnostic nuclear medicine investigation is a chain of different stages beginning with a request for a study, and ending with a final report (Bergmann et al., 1995). Usually the imaging procedure includes patient preparation for a study; compounding, quality control, dispensing and administration of radiopharmaceutical; data acquisition, processing, analysis; and interpretation of the images (Fig. 1). The Society of Nuclear Medicine has approved general procedure guidelines on imaging (Parker et al., 1996b) and on the use of radiopharmaceuticals (Callahan et al., 1996) in the practice of nuclear medicine.

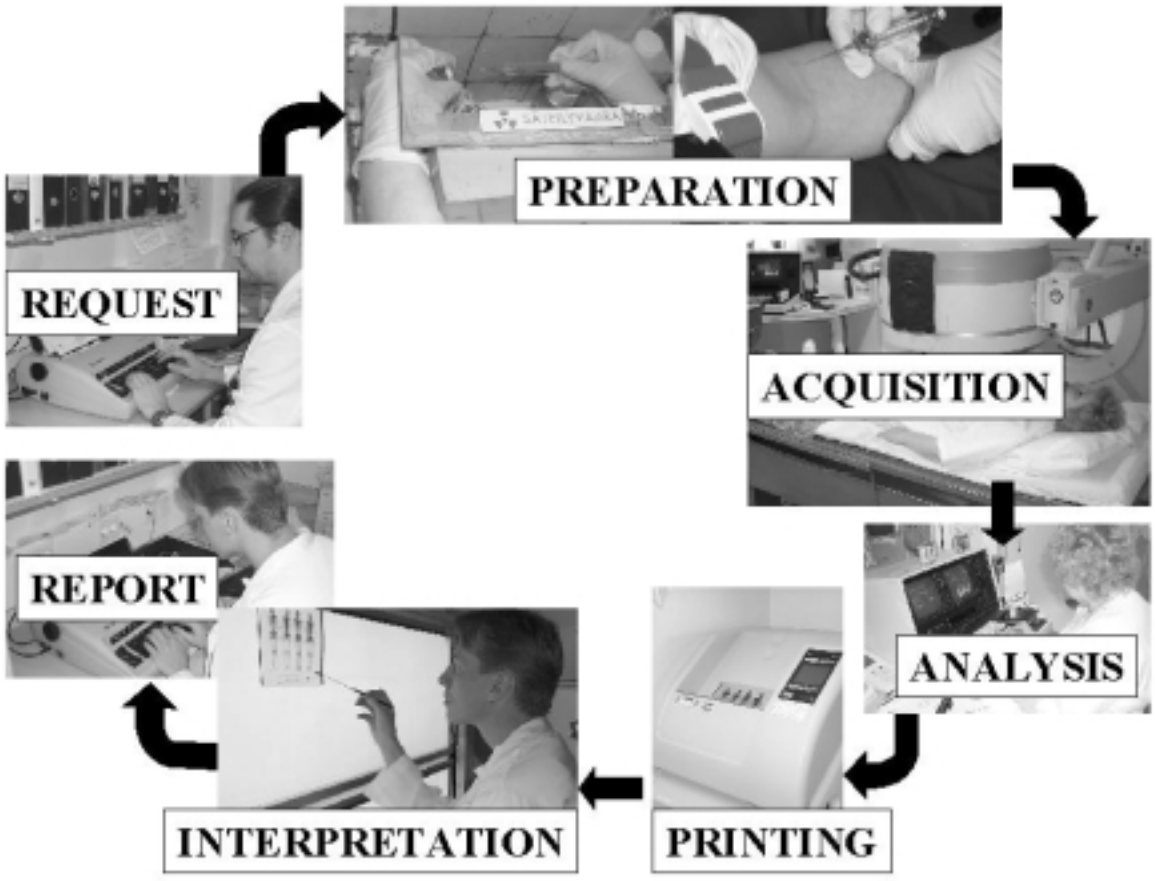


Fig.1. Imaging chain in nuclear medicine.

Quality assurance is one way to guarantee to the customers that the product is what they have requested. In nuclear medicine the customer is the patient and her/his clinician. The product is the whole study with accurate interpretation of images and relevant parameters. Quality requires optimal performance from the equipment, the best method for acquiring and processing the images and accurate interpretation (Cerqueira, 1997; Bergmann et al., 1995). Every step during the imaging sequence affects the final result. Most of the individual steps and the facility can and should be checked by the staff regularly which is called internal quality assurance. In addition, the whole diagnostic imaging chain needs to be checked independently by an outside observer. That is external quality assurance (Fig. 2).

An audition, in which the documentation of the clinical studies were studied has been made in Europe (Ball, 1998). The goal of those audits is good clinical practice (GCP) which should lead to good quality imaging. The best way to compare the quality of imaging between laboratories is a multicentre study with a human being afflicted with known diseases. Due to ethical aspects and radiation safety it is not possible. An analogue approach is to use organ-like phantoms.

Vauramo (1970) was among the first researchers to design phantoms to increase nuclear medicine imaging quality in Finland. He suggested that in the future each apparatus will be accompanied by its figure of merit showing its performance, based on measurements made with a standard international phantom. Koskinen (1989), developed a phantom for the comparison of the performance of single photon emission tomography (SPET) systems. He made one of the first comprehensive multicentre comparisons of SPET in Finland. Toivanen (personal communication) compared laboratories with a (NEMA) phantom. Measurements were pointed to the performance of the gamma cameras and the results showed severe variation. Kärkkäinen (1991, 1992) was the first to make comparisons with an anthropomorphic phantom to evaluate total performance of the bone imaging systems. The results showed large variations in the performance of the different laboratories.

Many international and national multicentre studies with phantoms (Volodin et al., 1985; Souchkevitch et al., 1988; Bergmann et al., 1990; Skretting et al., 1990, Hart, 1997) have failed to demonstrate the role that various instrument variables and technical procedures play in the whole imaging chain. This may be because the relationship between separate parts of the imaging chain is so complex that the quality depends to a large extent on human factors rather than on individual instrument performance. That is why most of those separate parts have to be taken into account in multicentre comparisons.

External quality assurance in Finland has been performed by Labquality Ltd. since 1971 (Labquality Ltd., Helsinki, Finland, is certified by the standard SFS-EN ISO 9002 and is a WHO Collaborating Centre for Education and Training in Laboratory Quality Assurance). National surveys included mainly clinical chemistry, haematology, microbiology and other related areas (Labquality news, 1996). The aim of this study was to apply those external quality assessment schemes in diagnostic nuclear medicine. The first test included the project for nation-wide quality assurance part II in Finland. It dealt with the bone imaging and brain perfusion SPET (I). Following surveys were organised by Labquality Ltd.. The first was performed in 1994 for bone imaging, the second looked at brain perfusion SPET in 1995 (II) and the third considered myocardial perfusion SPET in 1996 (III). Also, in 1996 and in 1997, the quality of bone imaging reports was evaluated. For dynamic renal imaging a new phantom was developed (IV). The phantom was imaged in 19 hospitals in 1997.

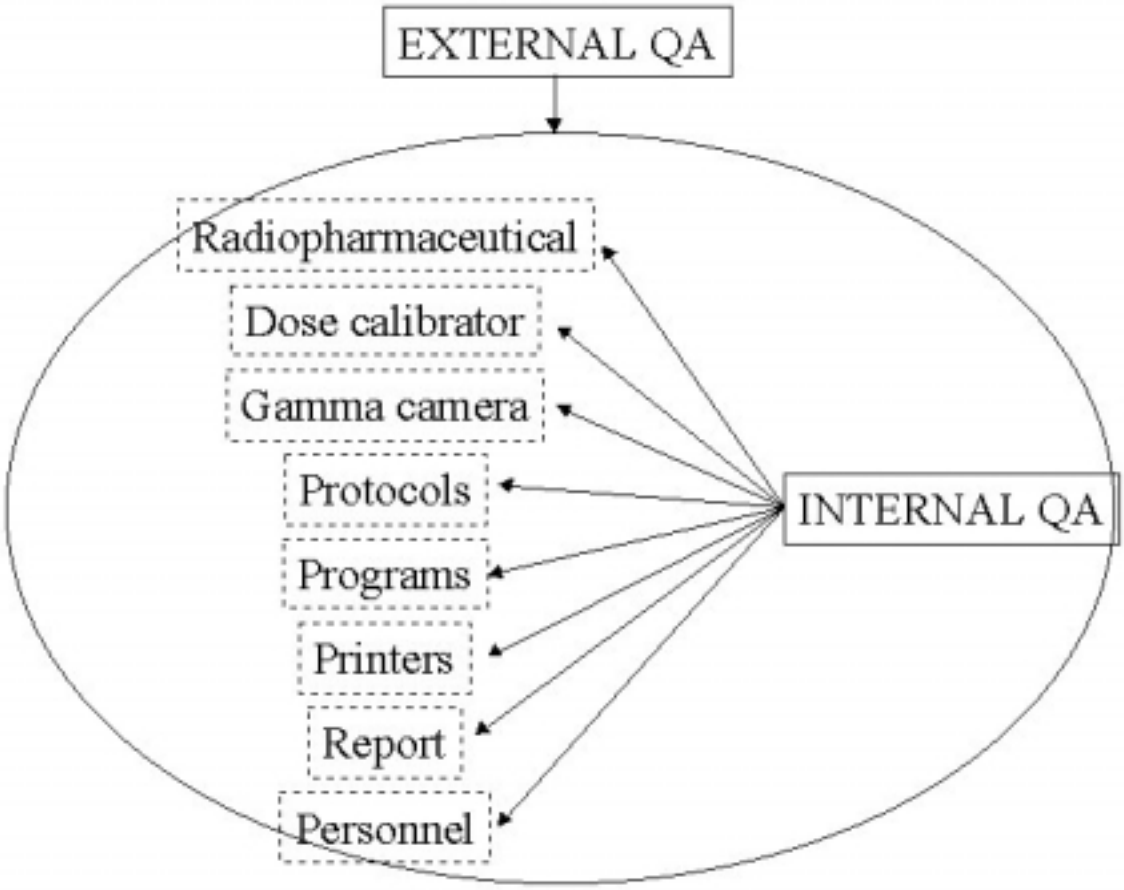


Fig.2. Schematic presentation of internal and external quality assurance (QA) in nuclear medicine imaging.

2. REVIEW OF THE LITERATURE

2.1. Nuclear medicine

2.1.1. Bone imaging

One of the most common type of examination in nuclear medicine is radionuclide bone imaging. It is a sensitive diagnostic imaging study used to detect the presence or extent of primary and secondary bone disease. It can often detect abnormalities before x-ray-imaging studies are positive, because metabolic changes usually precede anatomic changes. Examination of the entire skeleton is facilitated because the radiopharmaceutical is distributed throughout the body. Bone imaging may be indicated in the management of patients with neoplastic disease, occult fracture, osteomyelitis etc. (Donohoe et al., 1996). It is the first choice in routine for follow-up of asymptomatic patients with metastatic bone disease of the skeleton (Soderlund V, 1996). The haematogenous spread of the two most common malignancies (breast and prostatic carcinoma) is to the axial skeleton, and over 90 % of metastases will lodge in the bone marrow prior to extension into the osseous structures (Van der Wall, 1994).

Before imaging several factors merit consideration. One is the effect bone imaging will have on patient management. The referring physician does the consideration and should consult a nuclear medicine specialist in difficult cases. Imaging begins at the patient preparation, following the planning of the procedure. Information pertaining to performing procedure, questions to be answered and patient history etc., are essential in order to achieve relevant results.

Images are acquired usually two to five hours after injection of the radiopharmaceutical. The most common is a whole-body imaging involving planar images of the skeleton, including anterior and posterior views. Multiphase images consists of blood flow images (instantly after injection), immediate images (within 10 minutes) and delayed images (2 to 5 hours after injection). Additional views or SPET are obtained as a portion of the skeleton.

Generally no special processing of planar images is required. A nuclear medicine specialist who is informed about the course of the study should perform interpretation and reporting. The interpreter should know the sources of errors in the whole imaging system, and reports should include the parts generally recommended. The Society of Nuclear Medicine has written guidelines to promote the cost-effective use of high quality bone imaging procedure (Donohoe et al., 1996). Table 1 lists the most important aspects of a radionuclide bone examination.

Table 1. Main aspects of radionuclide bone imaging.

Indications	-	neoplastic diseases, occult fracture, osteomyelitis, avascular necrosis, arthritis, reflex sympathetic dystrophy, bone infarcts, bone graft viability, unexplained bone pain, prior to palliative therapy
Patient preparation	-	hydration between injection and delayed imaging, urination immediately prior to imaging, drinking of plenty of fluids for at least 24 hours
Pertinent information	-	questions, medical history, symptoms, physical findings, results of prior imaging and examinations (relevant laboratory test results e.g. PSA)
Precautions	-	should be deferred in pregnant women
	-	breastfeeding discontinued for 24 hours
Radiopharmaceutical	-	^{99m}Tc-labeled diphosphonates or pyrophosphates
Dose	-	adults: 740-1110 MBq, 11-13 MBq/kg more for markedly obese patients
	-	for children in accordance with the recommendations of EANM Paediatric Task Group
Acquisition	-	flow: 30 frames immediately after the injection, 1-2 s per image
	-	blood-pool: within 10 min, 3-5 min per image
	-	delayed images: 2-5 hours (usually anterior and posterior whole body)
	-	spot imaging: first chest view of 500 000 – 1 million counts, same time with the rest images
	-	whole-body scan: determine count rate (anterior chest) so that anterior or posterior image contain over 1.5 million counts
Processing	-	dual intensity images
	-	images should be viewed on computer display to permit adjustment of contrast and brightness
Interpretation (Report)	1.	the course of the examination and technical quality of the images (the reason if suboptimal)
	2.	increased or decreased accumulations: the anatomic location, the distribution (focal, diffuse, etc.) and the shape (round, fusiform, linear, etc.)
	3.	the target to background ratio
	4.	abnormalities in soft tissues, renal activity/morphology, activity in the urinary collection system and bladder after voiding
	5.	conclusions
Sources of errors	-	urine contamination, injection area, implants, contrast materials, homogeneously increased activity ("superscan"), motion, collimator-to-patient distance, imaging too soon, soft tissue compression, other radionuclides, extraneous radioactivity, radiopharmaceutical degradation, purely lytic lesions, bladder activity

2.1.2. Brain perfusion single photon emission tomography

Functional brain imaging with SPET systems promises to become an important tool in routine clinical diagnosis because of the good availability of single headed SPET systems in central hospitals and the increase in potential applications of brain SPET in neurological and psychiatric diseases. The development of radiopharmaceuticals has made it possible to measure blood flow, perfusion and receptor distribution in the human brain in vivo (George et al. 1991). These measurements are useful for example in diagnosing cerebrovascular diseases, tumours, trauma, Parkinsonism, dementia, psychiatric diseases, epilepsy (Bartenstein et al., 1991; Beer et al., 1990; Holman et al., 1992a; Kuikka et al., 1990). Although, in Europe there is, among neurologists, psychiatrists, neurosurgeons and general practitioners, a significantly poor level of knowledge about radionuclide techniques of brain SPET (Messa et al., 1995).

Blood-brain barrier (BBB) is a functional concept of the brain. The function of the BBB is to regulate the passing of the substances between the blood and the brain. Radiopharmaceuticals are divided in two main groups: penetrating BBB and not penetrating BBB (George et al. 1991). Radiopharmaceuticals not penetrating BBB are used in brain blood circulation diseases and in localisation of brain tumours and internal bleedings. The brain blood volume is possible to measure with ^{99m}Tc-labelled red blood cells and plasma volume with ^{99m}Tc-labelled human serum albumin.

Radiopharmaceuticals penetrating BBB are divided to perfusion and receptor tracers. The most used perfusion tracer is ^{99m}Tc-HMPAO and ^{99m}Tc-ECD. A SPET study for brain perfusion requires that the radiotracer cross the BBB, distributes proportionally to regional cerebral blood flow and remains fixed in the brain for a sufficiently long time to permit imaging. Perfusion tracers have been used in the diagnosis of cerebrovascular diseases (acute stroke, ischemia), epilepsy and dementia (Bartenstein et al., 1991; George et al., 1991; Holman et al., 1992b).

In a SPET of the brain the method of acquisition affects to the imaging resolution. With old SPET systems, where the detector shape is circular, the shoulders of the patient prevent close distance rotation of the camera around the patient. Therefore SPET is studied in some hospitals with Neuropath acquisition (the camera rotates from back of the head to the face) when the camera is rotated only 180°. Attenuation correction could properly be performed only for 360° rotation. One way to rotate the camera closer to head with old systems is the use of slant-hole collimators. With newer systems the detector shape is rectangular and so the camera rotates near the patient's head. The optimal choice of collimator depends on the available count density (Madsen et al., 1992). Most manufacturers are now offering multiple detector systems. The most sophisticated acquisition system is probably ASPECT, which has a cylindrical crystal in which the head is placed inside. It has a great deal of sensitivity and resolution in time and space (Croft, 1990).

It has been stated (Messa et al., 1995) that there has been a significant lack of well-defined rules for quality assurance, data acquisition, data processing and analysis of brain SPET. It produces a wide range of image quality and interpretation. Recommendations for performing the brain perfusion SPET studies have been published (Kotzki et al., 1995) and recently by the Society of Nuclear Medicine (Juni et al., 1998).

Table 2. Main aspects of brain perfusion SPET.

Indications	-	cerebrovascular diseases, dementia, epilepsy
Patient preparation	-	consistent environment at the time of injection and uptake: quiet, dimly lit room
	-	patient's eyes and ears open
	-	patient comfortably seated
	-	intravenous access 10 min prior to injection
	-	explain importance of no head movement
	-	instruct patient not to speak or read
	-	no interaction with patient prior to, during, or up to 5 min post injection
Pertinent information	-	patient history, neurological exam, psychiatric exam, mental status exam, recent imaging studies and current medications and when last taken
Precautions	-	special care and monitoring with demented patients and patients with neurological deficits
Radiopharmaceutical and dose	-	^{99m}Tc-HMPAO (unstabilised and stabilised), 555-1100 MBq (fresh elute less than 2 h old from a generator eluted last under 24 h)
	-	^{99m}Tc-bicisate ECD, 555-1100 MBq
	-	for children in accordance with the recommendations of EANM Paediatric Task Group
	-	quality control for radiochemical purity determination on each vial prior to injection
Injection	-	HMPAO (unstabilised) from 10 to 30 min postreconstitution, for seizure patient as soon as possible after reconstitution (within 1 min)
	-	HMPAO (stabilised) from 10 min to 4 h
	-	ECD from 10 min to 6 h
Acquisition	-	after 90 min of HMPAO injection (60 min is acceptable)
	-	after 60 min of ECD injection (30 min is acceptable)
	-	maximise patient comfort, void before acquisition
	-	completed within 4 h postinjection
	-	multiple-detector or dedicated SPET camera preferable: matrix 128x128 or more, 3° angular sampling, pixel size 1/3-1/2 the expected system resolution
	-	for single detector unit: if field size is 400 mm and matrix 128x128, ideal number of projections is 125 over 360° (Hutton, 1996)
	-	fanbeam or other focused collimator preferable, high-resolution, ultra-high-resolution or slant hole is acceptable
	-	smallest radius of rotation possible
	-	continuous acquisition, step-and-shoot is acceptable
	-	total counts 5 million or more
Processing	-	filtering in three dimensions with low-pass filter (e.g., Butterworth)
	-	reconstruct at highest pixel resolution, sum slice after reconstruction
	-	attenuation and scatter correction preferable
	-	generate transverse slices relative to a repeatable anatomic orientation, coronal and sagittal slices orthogonal to the transverse
	-	images should be viewed on computer display to permit adjustment of contrast and brightness
	-	continuous colour scale, tresholding based on normal data base
Interpretation (Report)	1.	the course of the examination and technical quality of the images (the reason if suboptimal), evaluation of patient movement from project data, artefacts
	2.	extent and severity of defects, correlation with morphologic (CT, MRI) and clinical abnormalities
	3.	epilepsy: correlation with EEG and clinical observations, exact timing of injection relative to seizure, comparison of ictal and interictal studies
	4.	conclusions
Sources of errors	-	presence of sedating medications at the time of injection
	-	patient motion

2.1.3. Myocardial perfusion single photon emission tomography

Nuclear cardiology is widely available and a widely accepted non-invasive diagnostic tool in the diagnosis of cardiac disorders (Alexander and Oberhausen, 1995; Iskandrian and Giubbini, 1996). Injected radiolabelled compounds distribute in the tissue in proportion to regional blood flow. Regions with higher blood flow at the time of the tracer injection will receive a higher concentration of the injected isotope compared to adjacent regions having lower flow. The myocardial distribution of tracer is compared between stress and rest to define infarct (constant defect) and ischemic areas (reversible defect).

Radiopharmaceuticals used for myocardial perfusion imaging are thallous chloride ^{201}Tl and several technetium labelled compounds: sestamibi, tetrofosmin, Q12 and teboroxime (Alexander and Oberhausen, 1995). An additional re-injection of thallium at rest provides better diagnostic information than does late redistribution imaging and offers the advantages of reducing total imaging time (Kayden et al., 1991; Kuijper et al., 1992; Van Eck-Smit et al., 1993). Some physical disadvantages (low gamma ray energy, long half-life) mean that ^{201}Tl is not ideal for cardiac imaging. Technetium-labelled compounds circumvent those limitations (Sullo et al., 1996). There have been found differences in defect size between ^{201}Tl and ^{99m}Tc-sestamibi (Maublant et al., 1992). Anyhow, ^{99m}Tc-sestamibi and ^{99m}Tc-tetrofosmin exercise-rest same-day SPET imaging is a suitable and accurate technique to identify patients with coronary artery disease (Sullo et al., 1996; Heo et al., 1997).

Myocardial images may be obtained as planar or tomographic images (SPET). The use of SPET is essential for the deeper insight of radionuclide distribution and for quantification (Hör, 1996). The choice of instrumentation (camera, collimator) sampling (radius of rotation, matrix size, number of planar images) and reconstruction methods (filter, iterative or noniterative algorithm) significantly affect to accuracy of SPET images (Rosenthal et al., 1995; Hutton, 1996). Many researchers advocate the use of 360° acquisition for quantitative work, and most centres routinely use 180° acquisition without attenuation or scatter correction. When nonuniform attenuation compensation is included in the reconstruction, the count density in the left ventricular wall is nearly identical for 180° and 360° SPET images (LaCroix et al., 1998). The availability of transmission data provides a practical method for scatter correction to 180° myocardial SPET (Hutton et al., 1996).

The standardisation of nuclear cardiology procedures has been an urgent problem of international interest (Hör, 1985). Nuclear cardiology should produce the same and reproducible results within a defined margin of error. Lack of standardisation of study conditions, data acquisition parameters, analysis and interpretation of the images produce differences between hospitals. A great step towards standardised nuclear cardiology in Europe was the attempt to product a data base for cardiac radionuclide studies by COST B2 Working Group II (Bourguignon et al., 1993). There are several recommendations for the protocols of myocardial perfusion SPET (Standardization of cardiac tomographic imaging, 1992; Bourguignon et al., 1993; Maddahi et al., 1994; Strauss et al., 1998). The most important aspects are seen in table 3.

Table 3. Main aspects of myocardial perfusion SPET.

Indications	-	evaluation of coronary artery disease; presence, location, extent and severity of myocardial ischemia and scar; determination of significance of anatomic lesions detected by angiography; myocardial viability; prognosis and monitoring of treatment effect
Patient preparation	-	4 hour fasting before stress study, remove radiopaque objects from the area of the thorax, patients should be hemodynamically and clinically stable for a minimum of 48 hours prior to exercise test, medications should be withheld for diagnostic studies if possible: cardioactive drugs must be discontinued for 7 plasmatic half-lives (e.g. 3 h for short-acting nitroderivatives, 48 h for beta-blockers and 48 h for calcium antagonists and long-acting nitrates)
Pertinent information	-	medical history: indication, medications, symptoms, risk factors, prior procedures; cardiorespiratory examination; 12-lead ECG; diet and insulin optimisation for diabetic patients
Precautions	-	unstable angina with recent (< 48 hour) angina, congestive heart failure, myocardial infarction within 2-4 days, uncontrolled systemic or pulmonary hypertension, untreated life-threatening arrhythmia's, AV-block, acute myocarditis, acute pericarditis, severe mitral or aortic stenosis, severe obstructive cardiomyopathy, acute systemic illness, conditions that may interfere with exercise, lack of life support instrumentation and emergency drugs and certified physician
Radiopharmaceutical and combined rest and stress dose	-	^{210}Tl-chloride, 74-150 MBq
	-	^{99m}Tc-sestamibi, 750-1100 MBq
	-	^{99m}Tc-tetrofosmin, 750-1500 MBq
	-	in the single-day ^{99m}Tc-studies the second dose should be at least three times the amount of the first dose
	-	a fat-rich meal or drink after sestamibi injection
Timing of the injection	1.	heart rate is at least 85 % of the predicted maximum (220-age)
	2.	on the appearance of ECG abnormalities of ischemic type
	3.	when exercise is stopped prematurely for clinical symptoms
	4.	in the event of arrhythmia's or hypotension
	-	exercise should continue at least 1 min after injection
Acquisition	-	heart close to the center of rotation
	-	for the field size of 400 mm and matrix 64 x 64, ideal number of projections is 48 over 180° (Hutton, 1996)
	-	duration of acquisition varies with the radiopharmaceutical and protocol (for above protocol: 30 sec/image for ^{201}Tl and low-dose ^{99m}Tc and 25 sec/image for high-dose ^{99m}Tc)
	-	ECG gating on ^{99m}Tc radiopharmaceutical studies with nonradiopaque electrodes and gating device, 8 - 24 frames per cardiac cycle (at exercise and at rest with two-day protocol and at higher dose acquisition with single-day protocol)
Processing	-	corrections for nonuniformity (flood source image containing 30 million counts), attenuation and scatter
	-	either a filtered backprojection or iterative reconstruction
	-	images should be normalised to ensure comparability between rest and stress
	-	short, vertical long and horizontal long axis slices in a standardised format with orientations and other relevant data displayed (colour table etc.)
	-	computer assisted quantitative analysis (polar map)
	-	images should be viewed on computer display to permit adjustment of contrast and brightness
	-	projection data should be reviewed as a cine display to detect patient motion
	-	ECG gated data should be evaluated both as summed and in a cinematic format
Interpretation (Report)	1.	the course of the examination and technical quality of the images (the reason if suboptimal), evaluation of patient movement from project data, artefacts
	2.	areas of decreased radiopharmaceutical concentration: size and severity
	3.	regional wall motion, thickening and ejection fraction (ECG gated study)
	4.	conclusions
Sources of errors	-	nonintravenous injection, patient motion, suboptimal stress level, inappropriate image processing, attenuation artefacts, ROI placement

2.1.4. Dynamic renal imaging

Dynamic radionuclide renal imaging (renography) gives functional and structural information about kidney and urinary tract non-invasively. It is a diagnostic tool in patients with suspected renovascular hypertension and obstructive nephropathy (Taylor and Nally, 1995; Fommei and Volterrani, 1995; Woolfson and Neild, 1997). Captopril, an angiotensin-converting enzyme inhibitor (ACEI), induced functional renal insufficiency in patients with bilateral renal artery stenoses or unilateral stenoses in a solitary kidney is the basis for the non-invasive ACEI renography (or captopril renogram test) for renovascular hypertension. Diuretic renography, where a physiological bolus of urine is generated by the stimulus of a potent diuretic during renography, has been adopted as a clinical management tool to assist in differentiating the various causes of hydronephrosis (HN) or hydroureteronephrosis (HUN) from that of obstruction (Conway, 1992).

Tracers containing technetium are currently the agents of choice for dynamic imaging of the kidneys. The radiation doses for ^{99m}Tc-diethylenetriaminepentaacetic acid (DTPA) and ^{99m}Tc-mercaptoacetyltriglycine (MAG3) are very similar and much lower on a per unit injected activity than ^{131}I-hippurate (OIH) (Stabin et al., 1992). DTPA was previously used tracer but MAG3 gives better image quality being an excellent renal radiopharmaceutical in routine use (Al-Nahhas et al., 1988).

Availability of three different radiopharmaceuticals, multiple quantitative parameters and variable acquisition protocols makes renal imaging a complex subject (Taylor and Nally, 1995). Differences in background subtraction can generate significant errors in measuring relative function (Taylor et al., 1997). Usually calculated parameters are time to reach maximum activity (Tmax), 20-min/maximum activity ratio and relative uptake. Deconvolution analysis is needed for the proper derivation of mean transit time (MTT) (Cosgriff et al., 1992).

There is a failure to standardise protocols and rigorously evaluate diagnostic techniques (Woolfson and Neild, 1997). Interpretation of the renogram shows poor sensitivity and post-test probability in comparison to the angiographic diagnosis (Schreij et al., 1995). Cosgriff et al. (1992) published recommendations for routine renography based on discussions of a round table meeting with the representatives of seventeen UK departments. The scientific committee of The Radionuclides in Nephrourology Group has developed consensus reports on the use of radionuclides to detect renovascular hypertension and obstructive uropathy (O'Reilly et al., 1996; Taylor et al., 1996) and the Society of Nuclear Medicine has published a procedure guideline for diagnosis of renovascular hypertension (Taylor et al., 1998). Main aspects of these recommendations are seen in table 4.

Table 4. Main aspects of dynamic radionuclide renography.

Indications	-	renal function, reflux nephropathy, acute renal failure
	-	renovascular hypertension (ACEI renography): abrupt or severe hypertension, hypertension resistant to medical therapy, abdominal or flank bruits, unexplained azotemia, worsening renal function during therapy with ACEIs, grade 3 or 4 hypertensive retinopathy, occlusive disease in other vascular beds, onset of hypertension before age 30 or after age 55
	-	outflow obstruction, hydronephrosis and hydroureteronephrosis (diuresis renography)
Patient preparation	-	7 ml water/kg body weight 30-60 min before the study
	-	ACEI renography: ACEIs withheld for 2-5 days, captopril 48 h and enalapril/lisinopril 96 h, fasting 4 h
Pertinent information	-	patient history, physical findings, medications
	-	ACEI renography: serum creatinine, resting blood pressure while sitting and standing
Precautions	-	ACEI renography: blood pressure and pulse monitoring at least every 10-15 min after ACE, intravenous line in high-risk patients, a patients blood pressure should be at least 70 % of baseline before sending home
Radiopharmaceutical and dose	-	^{99m}Tc-MAG3, 37-370 MBq
	-	^{99m}Tc-DTPA, 37-370 MBq
	-	for children in accordance with the recommendations of EANM Paediatric Task Group
Protocol and interventions	-	ACEI renography: 2 day - ACEI renography on the first day and baseline renography if needed; 1 day – baseline first (dose 37 MBq) and ACEI second (200-400 MBq); 25-50 mg captopril or enalaprilat crushed and dissolved to 150-350 ml water p.o.
	-	diuresis renography: furosemide 0.5 mg/kg body weight i.v. slowly; in standard diuresis renography data are collected for 20 min before furosemide injection (F+20); alternative methods F-15 and F+0; data collection should continue 15 min after the diuretic is administered
Acquisition	-	patient should void before beginning of acquisition
	-	large field-of-view camera, all purpose collimator
	-	matrix size 128x128
	-	heart, kidneys and bladder included in the field of view
	-	peak background subtracted kidney count rate 200 counts/s and for deconvolution renography 1000 counts/s (parenchyma 400 counts/s)
	-	position: supine (ACEI, less movement, kidney depth variation minimised, less risk for patients fainting) or sitting reclining against camera face (normal hydrostatic effects on urine flow, no absorber)
	-	dynamic flow: 1-3 s per frame up to 60 s
	-	remainder of the study 10 s per frame
	-	total acquisition time 30 (ACEI) – 35 (diuresis) min
	-	postvoid image is recommended
Processing	-	display 15 serial 2 min "analogue equivalent" images for 30 min renogram
	-	perform background subtraction using ring, elliptical or perirenal ROI (inferior ROI below kidneys is not acceptable)
	-	display renogram curves from ROIs assigned to the renal cortices and/or the whole kidneys (exclude pelvis and calyces)
	-	calculate relative uptake in the 1-2 or 1-2.5 min interval after injection (MAG3) or 2-3 min (DTPA), the time to maximum activity (Tmax), a 20 min/maximum ratio and renal parenchymal transit time (ACEI renography)
Interpretation (Report)	1.	the course of the examination and technical quality of the images (the reason if suboptimal), evaluation of patient movement, artefacts
	2.	the position, uptake and structure of the kidneys and urinary tract
	3.	parameters Tmax, 20 min/maximum and relative uptake
	4.	visual interpretation of the curves: effect of interventions
	5.	high, low or intermediate probability of disease (ACEI renography)
	6.	conclusions
Sources of errors	-	existing clinical and renographic results must be interpret with some caution because the protocols are complex and the diagnostic criteria are not well standardised

2.2. External quality assurance

2.2.1. Standardisation

International societies have established task groups in order to standardise studies in nuclear medicine (Bauer and Pabst, 1985; Bergman et al., 1995; Vauramo et al., 1990; Parker et al., 1996b). The ultimate aim of establishing standards is accepted world-wide but has not yet been realized. Quantitative functional parameters assessed by different institutions are not comparable. Standardisation of investigations is essential for improving the acceptance of nuclear medicine. A great step towards standardisation of nuclear medicine investigations has been made by The Society of Nuclear Medicine which have approved 26 procedure guidelines for nuclear medicine practice (Balon et al., 1997; Bartold et al., 1997; Becker et al., 1996a, 1996b, 1996c; Callahan et al.,1996; Datz et al., 1997; Donohoe et al., 1996; Greenspan et al., 1998; Juni et al., 1998; Mandell et al., 1997a, 1997b, 1997c, 1997d; O'Reilly et al., 1996; Parker et al., 1996a, 1996b; Royal et al., 1998; Schelbert et al., 1998; Seabold et al., 1997a, 1997b; Silberstein et al., 1996; Strauss et al., 1998; Taylor et al., 1996, 1998; Wittry et al., 1997). Those are available via the Internet at www.snm.org. When applying those guidelines in Europe, one has to realize that there are social, economical, availability and legislation differences between United States and Europe (Iskandrian and Giubbini, 1996).

2.2.2. Accreditation, certification and proficiency testing

The American College of Radiology is preparing an accreditation program to cover all the imaging systems in a radiology department, including nuclear medicine (Cerqueira, 1997). The United States federal government has already started to regulate diagnostic imaging services. Standards and testing methods for mammography equipment has been established (Farria et al., 1994) and need to be developed and implemented very soon for nuclear medicine. In the Barnes and Hendrick (1994) study only 5856 mammography units out of 11652 (68 %) passed accreditation at the first attempt. The major reason for failure was inadequate clinical images. Their results support the requirement of equipment performance audits and raise the question of whether similar problems exist in other areas of medical imaging. Their accreditation program did not include an evaluation of the reports.

Certification of nuclear medicine physicians is being performed by several organisations in the USA. Training requirements for examinees and the content of these examinations vary between organisations. Physicians' quality assurance inside a radiology department may include double readings of images and sending of code cards (Lamki et al., 1990). To most people proficiency testing is the critical component of quality. The ultimate test is how well all components of an imaging chain can interact to arrive at an accurate and clinically relevant diagnosis. Testing the individual components cannot always predict the results. Cerqueira (1997) suggested that new measures need to be taken to assure that they are providing optimal quality studies.

2.2.3. Multicentre studies

Internal quality assurance performed by the user is now widely applied on a regular basis. Less well accepted is external quality assurance as an equally indispensable part of a quality assurance programme (Bergmann et al., 1990). It has been difficult to obtain a consensus opinion as to an ideal specification for a phantom for an international interlaboratory comparison

(Souchkevitch et al., 1988). The American College of Nuclear Physicians (ACNP) has made organ phantom programs which was limited in scope and relatively expensive as mechanical devices had to be made, shipped and imaged. An alternative method would be the digital image transfer of clinical studies. It could be used in certification of interpreters (Cerqueira, 1997). The feedback to the laboratories was considered to be an essential part of the surveys. The comparison of methods enables laboratories to adjust their own techniques and even their way of reporting (Skretting et al., 1990). The studies permit an assessment of the real situation within laboratories and with information feedback can lead to necessary improvement (Volodin et al., 1985).

3. AIMS OF THE PRESENT STUDY

The main purpose of the present study was to apply external quality assessment schemes in diagnostic nuclear medicine. Aims of the study were:

- to develop and test methods for external quality assurance of bone imaging, brain perfusion SPET, myocardial perfusion SPET and dynamic renal imaging

- to develop and test a phantom for dynamic renal imaging

4. MATERIAL AND METHODS

The participating hospitals were: the university hospitals of Helsinki, Kuopio, Oulu, Tampere and Turku and central hospitals of Helsinki (Aurora, Laakso, Malmi and Maria), Hämeenlinna, Joensuu, Jyväskylä, Kajaani, Karjaa, Kemi, Kokkola, Kotka, Lahti, Lappeenranta, Mikkeli, Pori, Savonlinna, Seinäjoki, Rovaniemi and Vaasa. I visited all the participating hospitals and made all the planned measurements with the same phantoms. Measurements consisted of the quantitative evaluation of imaging systems and qualitative assessment of images and reports. After data analysis and evaluation, every participating laboratory received its individual feedback as numerical results and anonymous graphical distribution plots of the other participating centres. They also received written instructions and recommendations.

4.1. The phantoms

Commercial organ-like phantoms were available for bone imaging, brain perfusion SPET and myocardial perfusion SPET and have been described in detail in the original papers (I-III). A new phantom was developed for dynamic renal imaging which is described in the paper IV.

4.2. Quantitative evaluation of the imaging systems

In the pilot survey (I) all measurements of the physical performance of the facilities were performed equally in each laboratory. Quantitative parameters were obtained according to each centre's routine acquisition protocol with the surveys organised by Labquality Ltd.. In the survey for brain perfusion SPET (II), a performance phantom was acquired with the same protocol as a routine brain perfusion SPET. In the second bone imaging survey in 1994, in the myocardial perfusion SPET survey (III) and in the renal imaging survey in 1997 quantitative data was obtained straight from the organ phantom data.

4.2.1. Accuracy and linearity of dose calibrators

During all surveys the accuracy of the dose calibrators was measured with a calibrated standard ^{57}Co-source (4, 173, 73, 173 and 144 MBq). Measured values were compared with the half-life corrected calculated values and expressed as a percentage error.

Since the year 1994, also the linearity of the calibrators was measured. A 2-ml syringe was filled to 1 ml with a ^{99m}Tc-water solution (1000 MBq). Activity was measured immediately and 3, 6, 24 and 30 hours after preparation. Measured values were compared with the half-life corrected calculated values. The results were expressed as a percentage error.

4.3. Qualitative assessment of the organ phantom images

In the bone imaging surveys (I) the interpreters who normally gave reports in each centre performed qualitative evaluation. They marked all accumulation sites from their phantom images on a diagrammatic thorax drawing.

The evaluation of the brain perfusion SPET images (II), the myocardial SPET images (III) and the organ phantom image sets of the dynamic renal imaging were separately performed by three nuclear medicine specialists who had over 20 years experience: one physicist and two physicians. They gave the score from one (poor quality) to five (excellent quality) according to what was the informative

appearance in each image set. They were familiar with the exact structure or the functioning of the phantoms and they had a consensus about what each image set should include.

4.4. Qualitative evaluation of the reports

Interpreters from each centre gave a routine report from organ phantom image set in the myocardial perfusion SPET survey (III). Points were given according to how well interpreters found defects.

In the dynamic renal imaging in 1997 all routine reports were evaluated separately by experienced three nuclear medicine physicians. They gave the score from zero (poor) to three (excellent) (with quarter point division) according to accepted criteria. Interpretation, description and overall quality were judged separately.

4.4.1. Quality of bone imaging reports

Bone imaging reports authentic situation in Finnish nuclear medicine laboratories was evaluated in a separate survey in 1996. Seventeen laboratories participated in the study. All laboratories were asked to send the first five bone imaging images and reports of the year 1996 to Labquality Ltd (letters were sent in March 1996). Images and reports were made anonymous and then circulated through three nuclear medicine specialists (three experienced nuclear medicine physicians) who also kept a consensus meeting. They gave the score from zero (poor) to three (excellent) from each image-report combination (with quarter point division). The report got a high score if it contained recommended parts and if the conclusions from images were correct. Interpretation, description and overall quality were judged separately. Also the physician's referrals were evaluated. The participants received feedback and recommendations how to improve the quality of the reports.

On the second part of the survey in 1997, seventeen laboratories participated. Five abnormal bone images were sent to hospitals and asked to give their reports from the images. The same three experts evaluated the reports according to accepted criteria from zero to three and gave feedback on the quality of the reports.

4.5. Pilot survey for bone imaging and brain perfusion single photon emission tomography in 1993

All routinely used bone scintigraphy and brain SPET systems in 19 laboratories were examined. Physical performance was measured with a NEMA resolution phantom and with a special SPET phantom (Koskinen, 1989). Total performance was evaluated with a transmission phantom simulating bone imaging of the thorax and with a two-dimensional Hoffman brain phantom (I).

4.6. Bone imaging survey in 1994

Eleven laboratories participated in the first bone imaging survey organised by Labquality Ltd (Helsinki). The survey was a part of an international survey organised jointly by the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA) (Hart, 1997). A bone transmission phantom of the thorax, differing from that used in 1993 was measured with the protocol, which was routinely used in each laboratory. The basic protocol was fixed by the WHO/IAEA interlaboratory comparison methodology. The major difference compared with the methods used in the pilot test was the use of a fillable flood source. In the pilot test a ^{57}Co flood source was used which produced count rates differing from clinical

count rates. The same radionuclide (^{99m}Tc) and the count rates as in clinical routine was used with the fillable flood source. The activity of the source was normalised so that it produced the same count rate through the phantom as a routine patient does. In the pilot test the low count rate presented problem especially with the whole body imaging.

The physicians who normally gave reports from clinical bone studies visually evaluated the images. They marked all the accumulation sites on a diagrammatic drawing. The sensitivity and the specificity were calculated for all accumulation sites and separately for rib and spinal accumulations. Also, regions of interest were drawn on two spinal and two rib accumulations of the digital images when possible. A reference area was drawn next to each accumulation to define normal rib and spinal accumulation. The contrast ratio of the accumulation to the reference area was calculated for each accumulation.

4.7. Brain perfusion single photon emission tomography survey in 1995

Twelve laboratories participated in the study. A 3-dimensional high resolution brain phantom was filled with a well-mixed solution of Tc-99m, water and detergent. Acquisition, reconstruction and printing were performed according to the clinical routine in each centre. Three nuclear medicine specialists blindly evaluated all image sets. The results were ranked from one to five (poor quality - high quality). Also a SPET performance phantom was filled with the same radioactivity concentration as the brain phantom. The parameters for the acquisition, the reconstruction and the printing were exactly the same as with the brain phantom. The number of detected "hot" (from 0 to 8) and "cold" lesions (from 0 to 7) were visually evaluated from hard copies. Resolution and contrast were quantified from digital images.

4.8. Myocardial perfusion single photon emission tomography survey in 1996

Nineteen nuclear medicine departments participated in the study. A myocardial phantom simulating clinical stress and rest conditions was filled with routinely used isotope solution (Tc-99m or Tl-201). The cardiac insert included three reversible defects (simulating ischemia) and two fixed defects (simulating infarct). The phantom was imaged and interpreted equally as a myocardial perfusion patient. Reconstruction, printout and reporting were performed according to clinical routine in each center. Three nuclear medicine specialists anonymously evaluated the quality of the image sets. Visual scores of the experts were ranked from one to five. Additionally, points were given, from 0 to 8, for study reports according to how well perfusion defects were detected. Quantitative points were calculated by comparing background subtracted and normalized counts from 12 regions of interest between stress and rest images.

4.9. Dynamic renal imaging survey in 1997

The simulation with the phantom was made in 19 Finnish nuclear medicine laboratories. Containers were filled with radioactive solution, which produce count rates close to clinical situations, and three patient cases were simulated in every laboratory. The simulated cases and the phantom are described in the paper IV. The analysis of the results was made according to the principles described above.

The true values for time to reach maximum activity (Tmax), time to half activity from maximum activity (T1/2) and the ratio between 20 min activity and

maximum activity (20 min/max) were defined straight from time schedules of the simulations. Other parameters were compared with average value of all hospitals i.e. mean transit time (MTT) and relative uptake. Tmax and uptake values were received from all laboratories. Simulated cases I and III were used for the comparison of Tmax values and the left kidney data of all three cases for the uptake values.

All image series of the case III (simulating hypertonia) were numbered, and sent to three experts (nuclear medicine specialists with over 20 years' experience: one physicist and two physicians) who were familiar with the functioning of the phantom. They evaluated all the series blindly and scored (1 - 5) each of them according to what was the informative quality of the series: display of the "analogue equivalent" images, background subtraction, display of the renogram curves and parameters.

All reports were numbered, and sent to three experts (physicians with over 20 years' experience and subspecialty in nuclear medicine). They scored descriptive and interpretative parts and the overall quality of the reports according to accepted criteria from zero (poor) to three (excellent) and gave feedback of the quality of the reports.

4.10. The feedback

After data analysis and evaluation, every participating laboratory received its individual numerical results and anonymous graphical distribution plots of the other participating centres. Laboratories received written instructions where specialists pointed out the major pitfalls and corrective actions of the imaging systems and protocols including reporting of the corresponding centre. Specialists also gave general recommendations based on international literature and national recommendations.

5. RESULTS AND DISCUSSION

5.1. Facilities and imaging procedures

All surveys showed that the age or performance of the facility, the acquisition or the reconstruction did not explain all the poor results of the qualitative evaluations. First study (I) showed severe scatter in physical performance of gamma cameras. The results of the following surveys were similar. The use of different collimators and newer gamma cameras is one corrective method, but of course, not always possible for some laboratories because of financial reasons.

Acquisition protocols varied between hospitals with all the nuclear medicine investigations studied. It partly reflects on the different facilities but also to the lack of knowledge of how facilities should be used in practice with a particular examination. The use of smaller patient-to-collimator distance, smaller radius of rotation, different matrix size or frame time could produce significantly better images. Although, variable protocols partly explain the uncorrelation of gamma camera age to the qualitative results. The same situation was found in the reconstruction of SPET images. There were variations in the filtering of raw data and in the use of corrections (attenuation, uniformity and centre of rotation). User can make changes to those parts to improve quality.

Formatting images was heterogeneous. There were almost as many image formatting methods as many laboratories. Most probably the reason is the relatively large number of different hard copy media and printer manufacturers with almost infinite number of colour tables and grey scale possibilities. In some cases the printer was not adjusted properly, thus modifying the shape of the actual image in the final hard copy, i.e. making ellipse from a round object. The user can also modify those parts of the imaging chain.

5.1.1. Dose calibrators

The percentage errors in accuracy and in linearity are shown in Table 5. Ten percent or less error in accuracy can be kept reasonably low for clinical use according to The National Radiation Safety Organisation (Säteilyturva-keskus, STUK). Only three laboratories during these five surveys had errors over that limit (hospitals 1, 2 and 20). Hospital number 2 purchased a new calibrator before the survey in 1997 that can be seen in results. Also, hospital number 1 bought a new calibrator in 1998. In linearity there were only two cases (hospitals 1 and 22) where the maximum error is over ten percent. The case of hospital number 22 is most probably due to a measurement error.

5.2. Quantitative performance and qualitative scores

Visual interpretation of printed organ-like phantom images defines the performance of a large part of the imaging chain. The preparation of the radiopharmaceutical, patient management and the interpretation are not included in that performance. The visual score is equal to the quantitative performance minus the loss of information by the ability of the printer to reproduce the selected colours or shades of grey and the perception of the colour table. Thus, when the quantitative results are high and the visual score is low, there is possibility for a better image quality by changing colour tables, printing parameters and maybe by purchasing a higher quality printer. The colour table used for printing is not necessarily the same that is used when looking the images from computer monitors. The colour table should be tested and adjusted for each printer used. If both the quantitative and the qualitative results were weak,

Table 5. Errors in accuracy and in linearity of dose calibrators during surveys from year 1993 to 1997.

		Accuracy, error (%)					Linearity, error (%)			
Hospital	Manufacturer	1993	1994	1995	1996	1997	1994	1995	1996	1997
1	A	-11,4	-5,0	-6,9	-	-	-12,9	-5,1	-7,3	-5,2
2	B	3,8	*	-2,7	-	-8,6	*	-5,9	-8,2	0,0
3	A	1,0	*	*	7,2	-7,3	*	*	4,8	5,0
4	C	-1,0	2,5	-1,5	-1,9	-4,6	0,4	1,4	1,8	3,4
5	D	*	*	*	*	-4,2	*	*	*	8,6
6	C	1,9	5,3	1,7	1,2	-2,6	-2,7	-1,9	-0,2	0,1
7	E	*	5,1	1,0	0,4	-2,4	3,7	-4,8	-1,4	6,5
8	F	*	*	*	-7,5	-2,4	*	*	-3,3	0,3
9	B	4,0	*	-5,3	-3,6	-2,2	*	-2,9	4,2	-1,0
10	C	0,9	*	*	-1,0	-2,1	*	*	2,1	1,8
11	C	6,0	*	*	*	-2,0	*	*	*	4,7
12	C	*	3,2	0,0	0,4	-1,0	-1,1	-4,7	1,6	1,6
13	F	*	*	*	2,0	-0,9	*	*	0,9	-3,7
14	C	*	*	*	*	-0,7	*	*	*	-6,0
15	F	3,7	-0,3	4,2	2,5	-0,7	-0,9	6,7	-0,3	0,7
16	C	2,0	5,3	*	1,6	-0,5	-1,8	*	-0,1	2,1
17	F	-9,3	-3,4	5,0	-3,8	-0,3	-5,0	-0,5	9,5	-3,5
18	C	1,9	*	2,1	2,7	-0,3	*	0,7	0,3	1,6
19	A	-3,7	0,2	*	-2,2	-0,2	-4,7	*	-2,0	1,0
20	G	*	*	*	-	*	*	*	-7,2	*
21	F	*	*	*	-2,9	*	*	*	-3,1	*
22	C	*	*	1,2	1,0	*	*	-	-1,2	*
23	C	1,9	*	1,0	*	*	*	-1,7	*	*
24	C	3,0	*	*	*	*	*	*	*	*
25	C	*	4,7	*	*	*	-2,7	*	*	*
26	H	*	10,7	*	*	*	5,9	*	*	*
Average		0,3	2,6	0,0	-2,7	-3,0	-2,0	-5,1	-0,5	0,9
SD		4,9	4,5	3,5	6,8	3,4	4,9	12,3	4,3	3,8

Hospitals and manufacturers are coded in order to maintain

Manufacturers in alphabetical order: Atomlab, Capintec, Picker, Radioisotope Calibrat
ARC,
VEB, Veenstra, Victoreen, Vinten.
* Not participated or

the corrective efforts should emphasise on equipment, acquisition and reconstruction.

The reasons for the wide variation in reported incidence may in part reflect scanning technique, equipment or methods, but it is probable that the most important variables are differences in the reporting of images and the subsequent investigation of abnormalities. Accuracy of reporting is probably the most important factor for overall performance (Hart, 1997).

5.2.1. Bone imaging reports

Results of the part I: the average scores of the quality were 2.2 ± 0.4 for overall quality, 2.3 ± 0.3 for descriptive part and 2.3 ± 0.5 for interpretation part. The average

scores of the referrals were 2.3 ± 0.3. Results of the part II: the average scores were 2.2 ± 0.6, 2.3 ± 0.6 and 2.1 ± 0.6, respectively. Thirteen of the laboratories participated in both surveys and their scores for overall quality are seen in Fig. 3. The

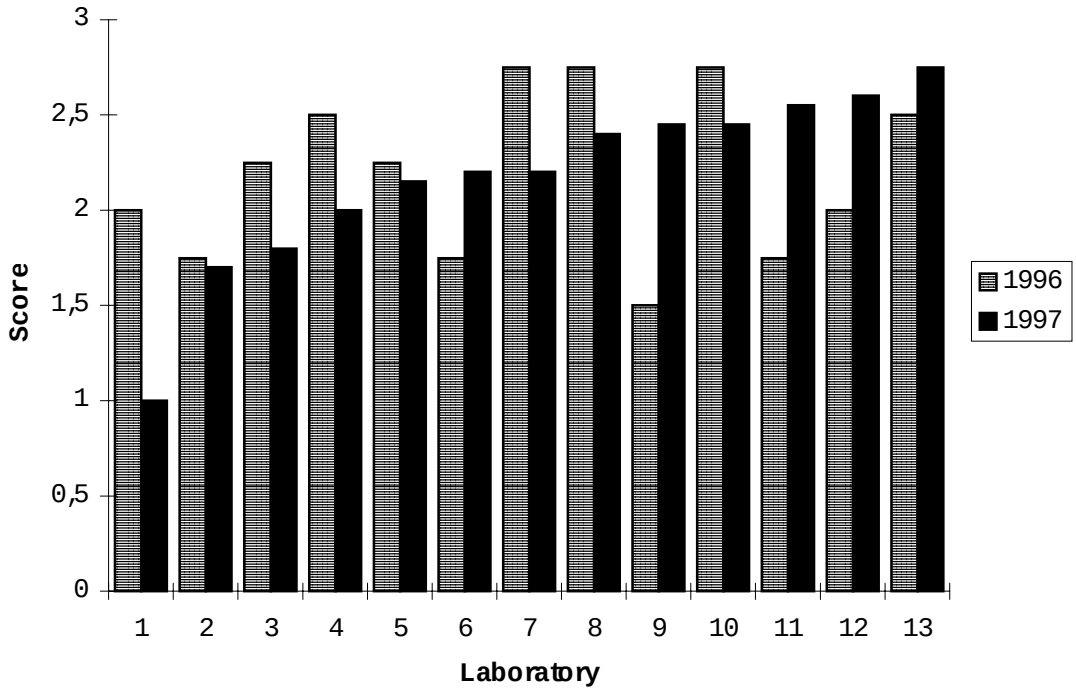


Fig. 3. Scores for overall quality of the bone imaging reports of those laboratories that participate in both surveys in 1996 and 1997.

quality of the reports was poor in some laboratories, which emphasised the need for external quality assurance of nuclear medicine reports. There was some difference between the results of the first and the second part. It can be seen from the Fig. 3 that five laboratories increased their overall quality. In the first part of the test interpreters read familiar and usually quite easy or normal bone images. In the second part the cases were more complicated. This is most probably the reason for the decrease of the overall quality in most of those laboratories.

5.3. Pilot survey

Manufacturer, age or the collimator of the gamma camera did not correlate with the physical performance of the imaging systems. Comparison of the physical and the total performance showed that the facility itself was not necessarily responsible for inaccurate findings from the test object. The use of dual intensity and digital images increased the sensitivity of the findings. The study (I) revealed the need for objective audit tests of bone scintigraphy and brain SPET systems in Finland.

5.4. Bone imaging

Sensitivity of all accumulations was 75% (range 52-86%), in 1993 it was 69% (28-100). For rib accumulations it was 78% (65-94), 72% (29-100) and for spinal accumulations 61% (0-100), 62% (0-100), respectively (I). One laboratory reported no spinal accumulations, which was probably mainly due to old facilities (Table 6, Fig. 4). An inquiry showed that all laboratories perform flood field uniformity checks at least once a week but there is a wide range of quality assurance methods and additional measurements. This study showed that the pilot round in 1993 caused changes in bone imaging procedures in some laboratories. The use of dual intensity images rose from 55 % to 73 %.

Table 6. Basic data and the results of the bone survey in 1994.

Hospital	Gamma camera					All accumulations		Ribs		Spine		Contrast	
	Manufacturer	Age (years)	Collimator	Acquisition	Image	Sens. (%)	Spec. (%)	Sens. (%)	Spec. (%)	Sens. (%)	Spec. (%)	Ratio	SD
1	3	11	DP	WB	SI	85,7	96,0	88,2	93,3	75,0	100	1,31	0,14
2	2	9	AP	S	SI	85,7	84,0	88,2	86,7	75,0	80,0	1,49	0,20
3	1	4	HR	WB	DI	85,7	76,0	94,1	66,7	50,0	90,0	1,38	0,16
4	3	1	AP	WB	DI, M	81,0	80,0	82,4	66,7	75,0	100	1,35	0,16
5	4	1	AP	S	DI	76,2	96,0	76,5	93,3	75,0	100	1,36	0,20
6	1	6	AP	WB	DI	71,4	100	64,7	100	100	100	1,32	0,20
7	1	10	AP	S	SI, M	71,4	100	76,5	100	50,0	100	1,39	0,20
8	5	2	HR	WB	DI	71,4	96,0	76,5	93,3	50,0	100	1,32	0,17
9	5	1	HR	WB	DI	71,4	92,0	76,5	100	50,0	80,0	-	-
10	1	3	HR	WB	DI	66,7	84,0	64,7	86,7	75,0	80,0	1,28	0,10
11	6	11	AP	S	DI	52,4	100	64,7	100	0,0	100	-	-
Average		5,4				74,5	91,3	77,5	89,7	61,4	93,6	1,36	0,17
SD		4,2				10,1	8,7	10,1	12,4	25,9	9,2	0,06	0,04

Hospitals and manufacturers are coded in order to maintain anonymity.
Manufacturers in alphabetical order: Adac, Elscint, GE, Siemens, Sigma and Toshiba.
AP = all-purpose, DP = diverging parallel, HR = high resolution. WB = whole body, S = static.
Image: SI = single intensity, DI = dual intensity, M = interpretation also from monitor.
Sens. = sensitivity, Spec. = specificity.

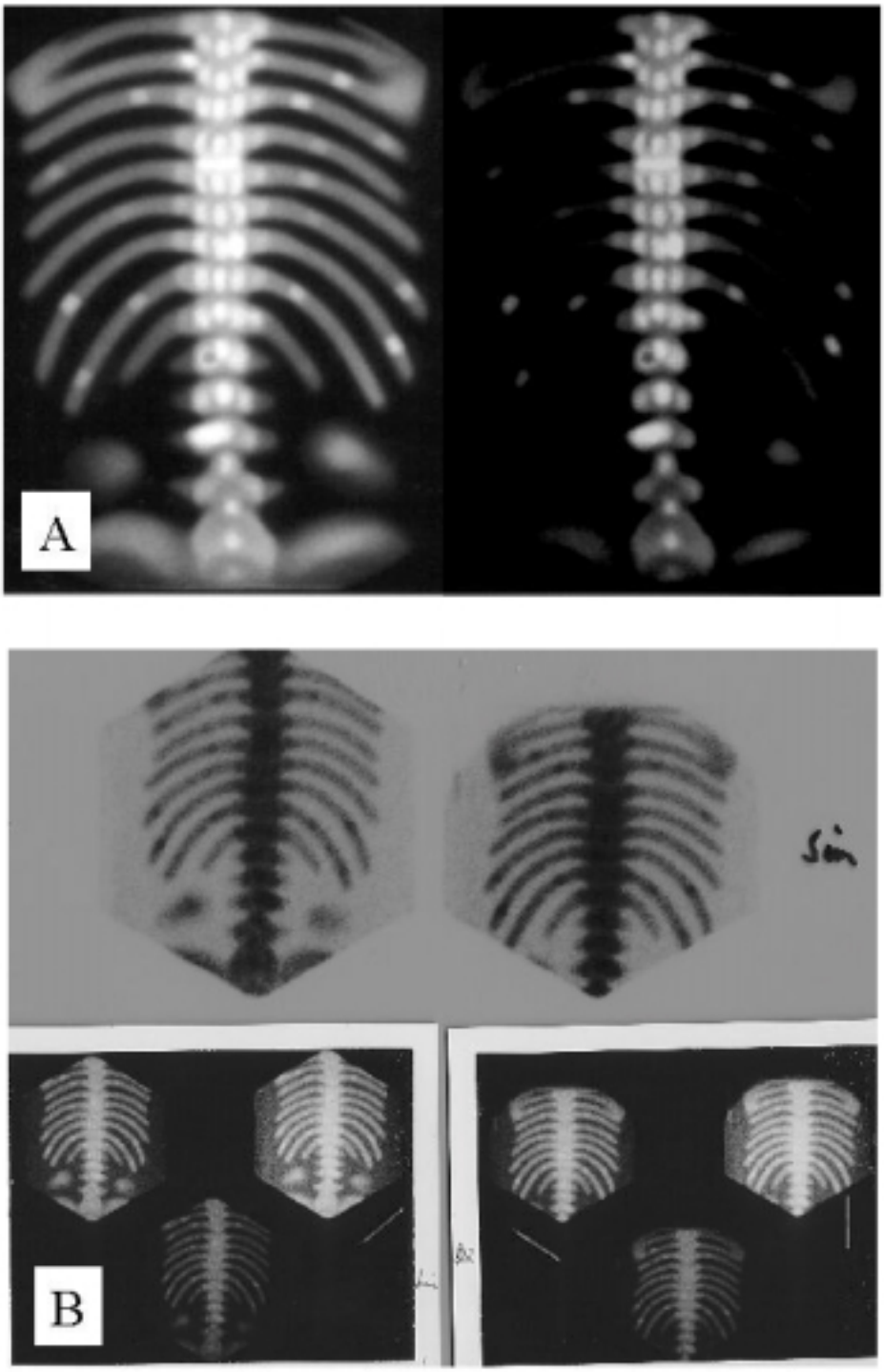


Fig. 4. A) The reference image set of the bone phantom and B) the worst image set according to the results.

5.5. Brain perfusion imaging

The average score for brain phantom images was 2.7 ± 0.8 (range from 1.5 to 4.5). The average diameter of the "hot" cylinders detected was 16 mm (from 9.2 to 20.0 mm) and the "cold" cylinders detected was 11 mm (5.9 - 14.3 mm) due to visual evaluation. Quantification of digital images showed that the hard copy was one reason for low quality images. The quality of the hard copies was good only in four laboratories and amazingly low with the others when comparing it to the actual structure of the brain phantom. The described quantification method is suitable for optimising resolution and contrast detectability of hard copies. This study revealed the urgent need for external quality assurance of clinical brain perfusion SPET images.

5.6. Myocardial perfusion imaging

Results for technetium studies (12 departments) were better than those for thallium (7 departments). Average visual scores of the experts were 3.7 ± 0.9 for all image sets, 3.2 ± 0.5 for thallium and 3.9 ± 0.6 for technetium users ($p = 0.003$). Five laboratories received mediocre score (< 3.0) which is sufficient for limited clinical use according to the specialists. Average points for the reports were 5.6 ± 2.1, 4.9 ± 1.5 and 6.5 ± 1.7 ($p = 0.051$) and for the quantitation were 8.2 ± 1.0, 7.9 ± 0.4 and 8.4 ± 1.1 ($p = 0.185$), respectively. The selection of collimators had significant effect on scoring, as well. There were seven out of 22 interpreters who did not detect the lateral 20 x 20 x 14 mm^3 defect, five of them used thallium. The present study demonstrated the heterogeneity of myocardial perfusion SPET in Finland. The participating laboratories used a wide scale of methods and, sometimes, inappropriate imaging protocols. The need for quality assurance in nuclear cardiology, correct use of SPET instrumentation and objective comparison of clinical studies is evident. The method described is suitable for external quality assurance and quality improvement of myocardial SPET imaging, and is recommended for regular use in nuclear medicine.

5.7. Dynamic renal imaging

Gamma camera images from the phantom were close to a real patient and the time activity curves seemed similar between laboratories but calculated parameters varied. The average error in Tmax was -2.4 ± 9.0 % (from -29.4 to +17.8 %), in T1/2 9.5 ± 24.6 % (-42.8 to +66.2 %) and in 20-min/peak ratio 3.7 ± 18.5 % (-50.0 to +81.7 %). The difference from average in uptake was 0.0 ± 9.4 % (-21.0 to +36.4) and in MTT 0.0 ± 24.9 (-50.8 to +58.3). Average scores of the image series and reports are seen in Table 7 and as a histogram in Fig. 5. The average scores for the reports were 2.1 ± 0.4 (range from 1.2 to 2.9) for overall quality, 2.0 ± 0.3 (1.4 to 2.8) for descriptive part and 2.2 ± 0.4 (1.4 to 2.9) for interpretation part. Hospital number 14 had two interpreters. The difference of their score shows slight interlaboratory variation. The difference between laboratories depends most probably on variations in analysis protocols and programs (Table 8). The number of participating laboratories was 19, the number of different acquisition protocols was 18 and the number of different analysis programs was 8. Also there were variations in positioning the regions of interest (ROI) for the background subtraction (Fig. 6).

Table 7. The results of the renography survey in 1997.

Hospital	Tmax Error (%)	SD	Uptake Difference (%)	SD	Image set Score	SD	Report Score	SD
1	0,9	1,9	5,0	6,9	2,8	0,7	2,2	0,3
2	1,6	1,4	2,0	2,7	3,5	0,7	2,8	0,2
3	2,2	3,5	12,7	20,5	3,6	0,5	2,1	0,3
4	3,7	4,9	5,9	2,8	3,4	0,4	2,1	0,3
5	4,4	5,5	3,8	5,3	2,8	0,8	2,0	0,4
6	4,5	4,3	2,9	4,1	4,2	0,5	2,3	0,4
7	4,5	4,3	3,1	4,7	3,9	0,4	1,9	0,4
8	4,7	4,6	5,4	7,8	2,9	0,8	2,4	0,2
9	4,8	5,6	5,7	6,0	3,3	0,3	2,1	0,3
10	5,2	4,9	14,4	16,1	3,3	0,7	2,9	0,1
11	5,9	7,1	4,0	4,5	3,3	1,2	2,3	0,2
12	6,6	5,2	4,7	5,7	3,4	0,4	2,0	0,4
13	7,0	9,3	3,6	4,0	2,4	0,7	2,1	0,3
14	8,0	5,1	2,9	4,3	2,8	0,8	2,0/1,7*	0,3/0,4*
15	8,3	7,7	11,0	13,3	3,0	0,9	2,0	0,3
16	13,2	4,1	16,6	12,0	2,6	1,4	1,7	0,5
17	13,2	18,6	1,6	1,7	2,8	0,9	1,2	0,4
18	13,8	12,0	2,2	2,8	4,1	0,9	2,1	0,4
19	16,3	11,3	3,5	5,5	2,8	1,1	2,6	0,3
Average	6,8	6,4	5,8	6,9	3,2	0,7	2,1	0,3
SD	4,4	4,0	4,4	5,0	0,5	0,3	0,4	0,1

Tmax = time to reach maximum activity.
Tmax and uptake values are average of absolute values.
* two interpretations.

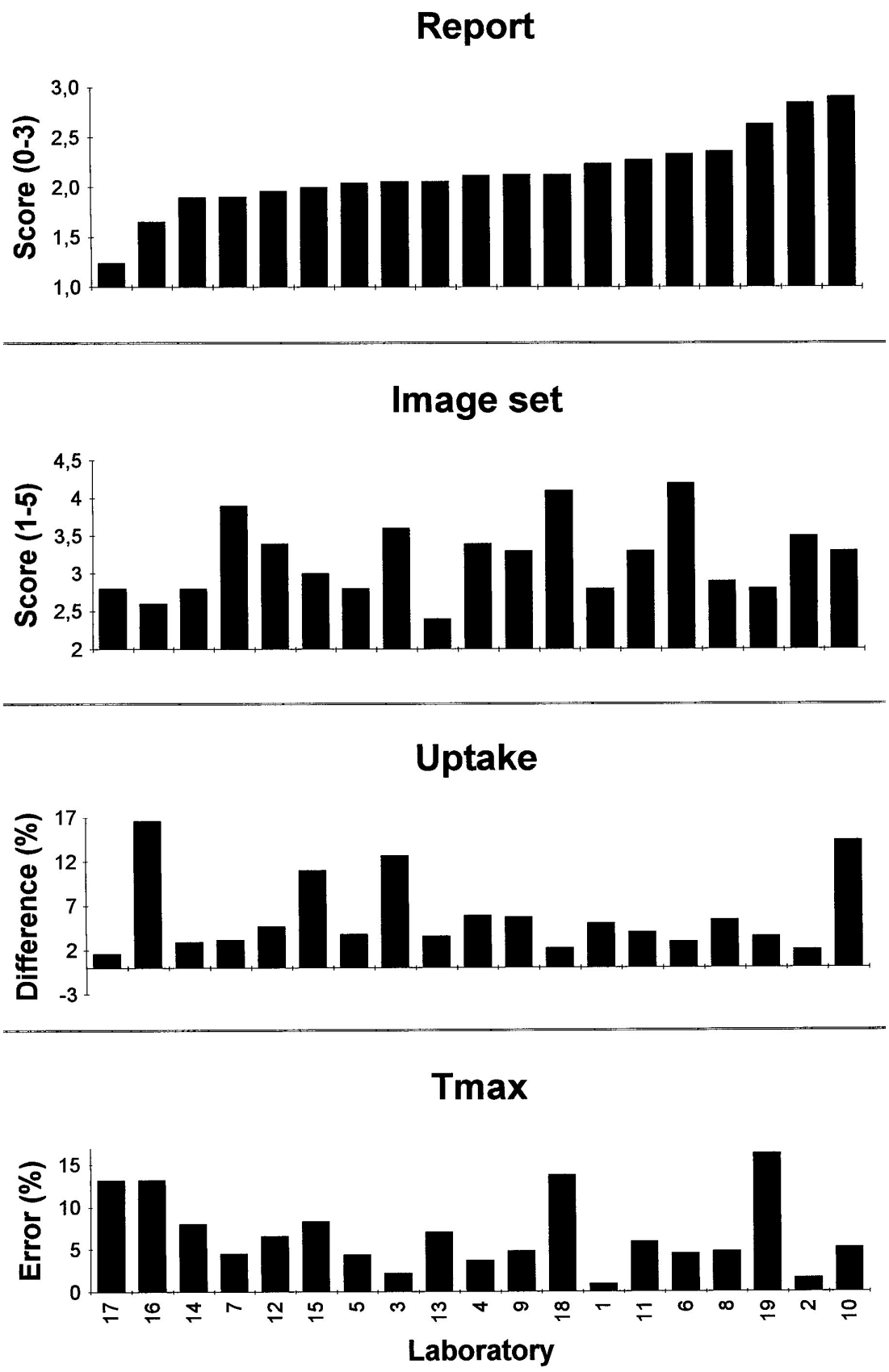


Fig.5. Histogram of the results of the renography survey.

Table 8. Acquisition parameters for a standard renography in nineteen participating hospitals.

Hospital	Tracer	Dose (MBq)	Void	Position	Acquisition protocol	Patients in 1996	Position of the background ROI	Analysis program
1	DTPA	110	0	sitting	60x1s+120x10s	30	circ	Hermes
2	MAG3	111	1	sitting	40x1s+120x10s	246	circ	Hermes
3	MAG3	110	0	supine	40x1s+60x20s	260	circ	Hermes
4	DTPA	150	0	supine	60x1s+20x15s+48x30s	115	kaud	GE
5	DTPA	111	1	supine	24x5s+56x30s	161	inflat	Toshiba
6	MAG3	110	0	supine	90x20s	210	lat + circ	Gamma-11
7	MAG3	100	0	sitting	120x20s	1130	lat	Hermes
8	MAG3	111	0	sitting	64x1+192x8s	86	lat	Elscint
9	MAG3	185	1	supine	16x2s+45x40s	45	inf	Toshiba
10	DTPA	185	1	supine	60x1s+60x30s	511	lat	In-house
11	MAG3	185	0	supine	60x1s+29x60s	82	lat	Adac
12	DTPA	370	0	supine	12x5s+87x20s	115	inflat	Toshiba
13	MAG3	100	0	sitting	46x1s+24x10s+26x60s	378	inf	Toshiba
14	DTPA	111	0	supine	60x1s+116x15s	179	inflat	Toshiba
15	DTPA	100	0	supine	90x20s	150	lat	Hermes
16	MAG3	148	1	supine	60x1s+12x5s+78x20s	170	infmed	Siemens
17	DTPA	148	0	supine	120x15s	244	lat	Gamma-11
18	MAG3	370	0	supine	30x1s+45x40s	320	inflat	Hermes
19	DTPA	370	0	supine	60x1s+50x30s	289	inflat+supmed	Gamma-11

Hospitals are coded due to maintain anonymity.
Void = 1 if patient is asked to void before examination, 0 if not.
lat = lateral, inflat = inferolateral, circ = circular, med = medial, kaud = kaudal, sup = superior.

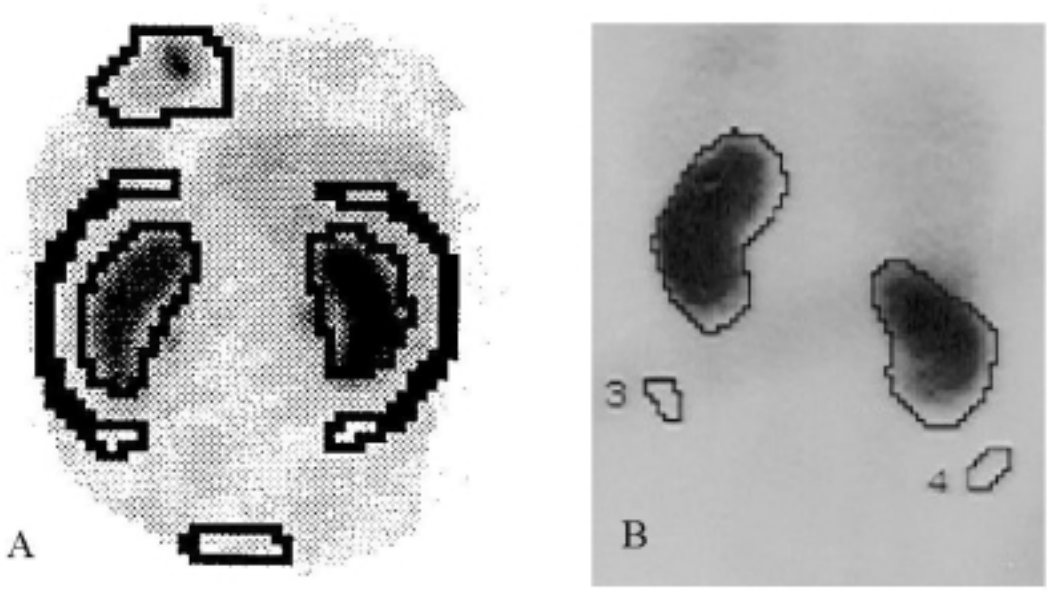


Fig. 6. A) Lateral regions of interest (ROI) for the background subtraction (recommended by the specialists) and B) inferior ROIs (not recommended).

5.8. Future suggestions

These external tests have shown that the whole diagnostic imaging chain needs to be checked independently by an outside observer. Our plan in the future is to continue these tests annually. The next topic will be lung perfusion and then for example five topics circulating in a five-year period: bone, brain, heart, kidneys and lungs.

In our surveys the number of participants have had in a range of 11 to 19. The planning, constructing and testing of the phantoms have taken from several weeks to several months depending on the topic. With commercial phantoms that time was shorter than with the new phantom (IV).

Until now, five external surveys have been performed. Hospitals were judged to be the worst or the best or mediocre according to a certain parameter. The laboratories, which received the worst and the best results, were always different. It can be concluded that laboratories have some particular examinations of their interest. They probably give less effort to other examinations. One reason is the personal interest of the staff of each laboratory or of the referrals. Another reason might be the fact that some laboratories lack certified and trained specialists and standardisation. Also, it has to be noted, that nuclear medicine is such a wide concept that it is a very severe challenge for any laboratory to know well about all those 70 different investigations. Also, the continuous development of new radiopharmaceuticals will increase the number of examinations variability (Van Rijk and Van Dongen, 1998).

One solution may be an independent, autonomous discipline of nuclear medicine, which will educate, publish, develop and expand the clinical nuclear medicine applications (Ell, 1998). With it we may succeed to educate a new generation of nuclear medicine specialists. This can lead to higher quality of imaging and patient care.

6. CONCLUSIONS

The aim of the present study was to develop methods and a phantom for external quality assurance of nuclear medicine investigations. In conclusion, the following observations and recommendations can be made:

1. Nuclear medicine imaging is heterogeneous in Finland and needs to be continuously tested by an independent outside observer.

2. The participating laboratories could compare their imaging quality with other laboratories in the country. They may exploit their poor results to speed up renewal of old equipment or good results to market their nuclear medicine examinations to clinicians. Surveys may also help us to avoid interpretation confusion between centres and between researches.

3. The laboratories producing the best and the worst quality varied between the surveys. The reasons are most probably the difficulty of nuclear medicine, the varying interest towards examinations and the lack of resources to concentrate enough to all procedures. Also, the lack of standardisation and harmonisation of investigation protocols plays a major role.

4. Most parts of the imaging chain can be tested with the organ-like phantoms including acquisition, reconstruction, printing and reporting.

5. The phantoms should simulate the clinical situation as closely as possible.

6. The test procedure has to be comparable and repeatable and it has to reflect the authentic situation in a given laboratory.

7. The measurements should be performed with the same phantoms in a supervision of one person to ensure comparability and time saving. The number of supervised laboratories per qualified person may be reasonable to reduce in countries with a large number of participating nuclear medicine departments. For example in the case of 100 participants, the test should be divided between four or five persons with exactly identical phantoms and instructions.

8. The test should include both quantitative and qualitative evaluations so that particular corrective actions can be recommended.

9. Feedback is an important part of the test protocol and should include recommendations from the latest international and national literature or from by-laws. The Society of Nuclear Medicine has written and approved procedure guidelines, which are suitable for defining the proper investigations. In this study our group of experts applied those general recommendations and other relevant publications to produce our national recommendations in nuclear medicine.

10. The dynamic renal phantom simulated a real clinical situation well. Function is repeatable and suitable for external quality assurance purposes.

External quality assurance has to be performed regularly.

7. REFERENCES

Alexander C, Oberhausen E: Myocardial scintigraphy. Semin Nucl Med 25: 195-201, 1995

Al-Nahhas A A, Jafri R A, Britton K E et al.: Clinical experience with ^{99m}Tc-MAG3, mercaptoacetyltriglycine, and a comparison with ^{99m}Tc-DTPA. Eur J Nucl Med 14: 453-462, 1988

Ball G J: Good clinical practice. In symposium proceedings: International Symposium "The Future of Nuclear Medicine". Tijdschr Nucl Geneeskd 20: 141-155, 1998

Balon H R, Fink-Bennett D M, Brill D R, et al.: Procedure guideline for hepatobiliary scintigraphy. J Nucl Med 38: 1654-1657, 1997

Barnes G T, Hendrick R E: Mammography accreditation and equipment performance. RadioGraphics 14: 129-138, 1994

Bartenstein P, Ludolph A, Schober O et al.: Benzodiatzepine receptors and cerebral blood flow in partial epilepsy. Eur J Nucl Med 18:111-118, 1991

Bartold S P, Donohoe K J, Fletcher J W, et al.: Procedure guideline for gallium scintigraphy in the evaluation of malignant disease. J Nucl Med 38: 990-994, 1997

Bauer R, Pabst H W: Inquiry to standardize nuclear-medical functional investigations. Eur J Nucl Med 11: 85-87, 1985

Becker D, Charles N D, Dworkin H, et al.: Procedure guideline for thyroid scintigraphy: 1.0. J Nucl Med 37: 1264-1266, 1996a

Becker D, Charkes N D, Dworkin H, et al.: Procedure guideline for thyroid uptake measurement: 1.0. J Nucl Med 37: 1266-1268, 1996b

Becker D, Charkes N D, Dworkin H, et al.: Procedure guideline for extended scintigraphy for differentiated thyroid cancer: 1.0. J Nucl Med 37: 1269-1271, 1996c

Beer H F, Blauenstein P A, Hasler P H et al.: In vitro and in vivo evaluation of iodine-123-Ro 16-0154: a new imaging agent for SPECT investigations of benzodiatsepine receptors. J Nucl Med 31:1007-1014, 1990

Bergmann H, Hoebart J, Kugi A: External quality control of gamma cameras - results of an inter-laboratory comparison study in Austria. Eur J Nucl Med 16: 23-28, 1990

Bergmann H, Busemann-Sokole E, Horton P W: Quality assurance and harmonisation of nuclear medicine investigations in Europe. Eur J Nucl Med 22: 477-480, 1995

Bourguignon MH, Sokole E B, Jones B et al.: Protocols for selection of cardiac radionuclide studies for use as a data base of normal studies and typical patterns of diseases. COST B2 Working Group II, in association with relevant working/task groups of the European Association of Nuclear Medicine and the European Society of Cardiology. Eur J Nucl Med 20: 59-65, 1993

Callahan R J, Chilton H M, Goodwin D A, et al.: Procedure quideline for imaging with radiopharmaceuticals: 1.0. J Nucl Med 37: 2092-2094, 1996

Cerqueira M D: Here in the USA: The elements of quality nuclear medicine. Eur J Nucl Med 24: 353-354, 1997

Conway J J: "Well-tempered" diuresis renography: its historical development, physiological and technical pitfalls, and standardized technique protocol. Semin Nucl Med 22: 74-84, 1992

Cosgriff P S, Lawson R S, Nimmon C C: Towards standardization in gamma camera renography. Nucl Med Comm 13: 580-585, 1992

Croft B Y: Instrumentation and computers for brain single photon emission computed tomography. Semin Nucl Med 20: 281-289, 1990

Datz F L, Seabold J E, Brown M L, et al.: Procedure guideline for technetium-99m-HMPAO-labeled leukocyte scintigraphy for suspected infection/inflammation. Society of Nuclear Medicine. J Nucl Med 38: 987-990, 1997

Donohoe K J, Henkin R E, Royal H D et al.: Procedure quideline for bone scintigraphy: 1.0. J Nucl Med 37: 1903-1906, 1996

Ell P J: Nuclear medicine as an independent medical speciality. In symposium proceedings: International Symposium "The Future of Nuclear Medicine". Tijdschr Nucl Geneeskd 20: 141-155, 1998

Farria D M, Basset L W, Kimme-Smith C, DeBruhl N: Mammography quality assurance from A to Z. RadioGraphics 14: 371-385, 1994

Fommei E, Volterrani D: Renal nuclear medicine. Semin Nucl Med 25: 183-194,1995

George M S, Ring H A, Costa D C et al.: Neuroactivation and neuroimaging with SPET. Springer-Verlag 1991

Greenspan B S, Brown M L, Dillehay G L, et al.: Procedure guideline for parathyroid scintigraphy. J Nucl Med 39(6): 1111-1114, 1998

Hart G: A UK survey of nuclear medicine imging performance using the TransBone anthropomorphic phantom. Nucl Med Comm 18: 668-672, 1997

Heo J, Powers J, Iskandrian A E: Exercise-rest same-day SPECT sestamibi imaging to detect coronary artery disease. J Nucl Med 38: 200-203, 1997

Holman B L, Devous M D: Functional brain SPECT: the emergence of a powerful clinical method. J Nucl Med 33:1888-1904, 1992a

Holman B L, Johnson K A, Gerada B et al.: The scintigraphic appearance of Alzheimer's disease: a prospective study using technetium-99m-HMPAO SPECT. J Nucl Med 33:181-185, 1992b

Hutton B: Letter to the Editor: Angular sampling necessary for clinical SPECT. J Nucl Med 37:1915-1916, 1996

Hutton B F, Osiecki A, Meikle S R: Transmission-based scatter correction of 180° myocardial single-photon emission tomographic studies. Eur J Nucl Med 23: 1300-1308, 1996

Hör G: Aspects of standardization in nuclear cardiology. Eur J Nucl Med 10: 478-479, 1985

Hör G. What is the current status of quantification and nuclear medicine in cardiology? Eur J Nucl Med 23:815-851, 1996

Iskandrian A S, Giubbini R: Comparison of nuclear cardiology in the United States and Europe. Q J Nucl Med 40: 27-34, 1996

Juni J E, Waxman A D, Devous M D Sr: Procedure quideline for brain perfusion SEPCT using technetium-99m radiopharmaceuticals. J Nucl Med 39: 923-926, 1998

Kayden D S, Sigal S, Soufer R, Mattera J, Zaret B L, Wackers F J Th: Thallium-201 for assessment of myocardial viability: quantitative comparison of 24-hour redistribution imaging with imaging after reinjection at rest. J Am Coll Cardiol 18: 1480-1486, 1991

Koskinen M O: Emissiotomografian laaduntarkkailu suomalaisissa sairaaloissa 1987. Technical research centre of Finland, Research reports 624, Espoo 1989

Kotzki P-O, Mariano-Goulart D, Quiquere M et al.: Optimum tomographic reconstruction parameters for HMPAO brain SPET imaging: a practical approach based on subjective and objective indexes. Eur J Nucl Med 22: 671-677, 1995

Kuijper A F M, Vliegen H W, Van der Wall E E, et al.: The clinical impact of thallium-201 reinjection scintigraphy for detection of myocardial viability. Eur J Nucl Med 19: 783-789, 1992

Kuikka J T, Länsimies E, Kuikka E O: Quantitative analysis of ^{99m}Tc-HMPAO kinetics in epilepsy. Eur J Nucl Med 16:275-283, 1990

Kärkkäinen A: Isotooppilääketieteen ohjelmistojen laadunvarmennus. Technical research centre of Finland, Tampere 1991

Kärkkäinen A: Luuston isotooppikuvausten pohjoismainen laaduntarkkailukierros. Kivilahti 1992

Labquality News: Annual review for 1995. 2/1996, ISSN 1237-5616, KP-Paino 1996

LaCroix K J, Tsui B M W, Hasegawa B H: A comparison of 180° and 360° acquisition for attenuation-compensated thallium-201 SPECT images. J Nucl Med 39: 562-574, 1998

Lamki L M, Haynie T P, Podoloff D A, Kim E E: Quality assurance in a nuclear medicine department. Radiology 177: 609-614, 1990

Maddahi J, Rodrigues E, Berman D S, Kiat H: State-of-the-art myocardial perfusion imaging. Nucl Cardiol 12: 199-222, 1994

Madsen M T, Chang W, Hichwa R D: Spatial resolution and count density requirements in brain SPECT imaging. Phys Med Biol 37: 1625-1636, 1992

Mandell G A, Cooper J A, Majd M, Shalaby-Rana E I, Gordon I: Procedure guideline for pediatric sedation in nuclear medicine. J Nucl Med 38: 1640-1643, 1997a

Mandell G A, Eggli D F, Gilday D L, et al.: Procedure guideline for renal cortical scintigraphy in children. J Nucl Med 38: 1644-1646, 1997b

Mandell G A, Cooper J A, Leonard J C, et al.: Procedure guideline for diuretic renography in children. J Nucl Med 38: 1647-1650, 1997c

Mandell G A, Eggli D F, Gilday D L, et al.: Procedure guideline for radionuclide cystography in children. J Nucl Med 38: 1650-1654, 1997d

Maublant J C, Marcaggi X, Lusson J-R, et al.: Comparison between thallium-201 and technetium-99m methoxyisobutyl isonitrile defect size in single-photon emission computed tomography at rest, exercise and redistribution in coronary artery disease. Am J Cardiol 69: 183-187, 1992

Messa C, Fazio F, Costa D C, Ell P J: Clinical brain radionuclide imaging studies. Semin Nucl Med 25: 111-143, 1995

O'Reilly P, Aurell M, Britton K, Kletter K, Rosenthal L, Testa T: Consensus on diuresis renography for investigating the dilated upper urinary tract. J Nucl Med 37: 1872-1876, 1996

Parker J A, Coleman R E, Siegel B A, Sostman H D, McKusick K A, Royal H D: Procedure guideline for lung scintigraphy: 1.0. J Nucl Med 37: 1906-1910, 1996a

Parker J A, Yester M V, Daupe-Witherspoon M E, Todd-Pokropek A E, Royal H J: Procedure quideline for general imaging: 1.0. J Nucl Med 37: 2087-2092, 1996b

Rosenthal M S, Cullom J, Hawkins W, et al.: Quantitative SPECT Imaging: A review and recommendations by the Focus Committee of the Society of Nuclear Medicine Computer and Instrumentation Council. J Nucl Med 36: 1489-1513, 1995

Royal H D, Brown M L, Drum D E, Nagle C E, Sylvester J M, Ziessman H A: Procedure guideline for hepatic and splenic imaging. J Nucl Med 39: 1114-1116, 1998

Schelbert H R, Hoh C K, Royal H D, et al.: Procedure guideline for tumor imaging using fluorine-18-FDG. J Nucl Med 39: 1302-1305, 1998

Schreij G, Van Kroonenburgh M J, Heidendal G K, Van der Pol H A, de LeeuW P W: Interpretation of captopril renography by nuclear medicine physicians. J Nucl Med 36: 2192-2195, 1995

Seabold J E, Palestro C J, Brown M L, et al.: Procedure guideline for gallium scintigraphy in inflammation. J Nucl Med 38: 994-997, 1997a

Seabold J E, Forstrom L A, Schauwecker D S, et al.: Procedure guideline for indium-111-leukocyte scintigraphy for suspected infection/inflammation. J Nucl Med 38: 997-1001, 1997b

Silberstein E, Taylor A Jr: Procedure guideline for bone pain treatment: 1.0. J Nucl Med 37: 881-884, 1996

Skretting A, Strandmyr E, Lindegaard M W: A Norwegian nationwide quality assurance project in nuclear medicine: total performance in bone scintigraphy measured with a new transmission phantom. Eur J Nucl Med 17: 10-14, 1990

Soderlund V: Radiological diagnosis of skeletal metastases. Eur Radiol 6: 587-595, 1996

Souchkevitch G N, Asikainen M, Bäuml A et. al. The World Health Organization and International Atomic Energy Agency second interlaboratory comparison study in 16 countries on quality performance of nuclear medicine imaging devices. Eur J Nucl Med 13: 495-501, 1988

Stabin M, Taylor A Jr, Eshima D, Wooter W: Radiation dosimetry for technetium-99m-MAG3, technetium-99m-DTPA, and Iodine-131-OIH based on human biodistribution studies. J Nucl Med 33: 33-40, 1992

Standardization of cardiac tomographic imaging. The Cardiovascular Imaging Committee, American College of Cardiology; The Committee on Advanced Cardiac Imaging and Technology, Council on Clinical Cardiology, American Heart Association; and Board of Directors, Cardiovascular Council, Society of Nuclear Medicine. J Nucl Med 33: 1434-1435, 1992

Strauss H W, Miller D D, Wittry M D, et al.: Procedure guideline for myocardial perfusion imaging. J Nucl Med 39: 918-923, 1998

Sullo P, Cuocolo A, Nicolai E, et al.: Quantitative exercise technetium-99m tetrofosmin myocardial tomography for the identification and localization of coronary artery disease. Eur J Nucl Med 23: 648-655, 1996

Taylor A Jr, Nally J V: Clinical applications of renal scintigraphy. AJR 164: 31-41, 1995

Taylor A, Nally J, Aurell M, et al.: Consensus report on ACE inhibitor renography for detecting renovascular hypertension. J Nucl Med 37: 1876-1882, 1996

Taylor A Jr, Thakore K, Folks R, Halkar R, Manatunga A: Background subtraction in technetium-99m-MAG3 renography. J Nucl Med 38: 74-79, 1997

Taylor A T Jr, Fletcher J W, Nally J V, et al.: Procedure guideline for diagnosis of renovascular hypertension. J Nucl Med 39: 1297-1302, 1998

Van der Wall H: The evaluation of malignancy: metastatic bone disease. In book: Nuclear Medicine in Clinical Diagnosis and Treatment, pp. 949-962. Ed. Murray I P C, Ell P J. Churchill Livingstone, Edinburgh, London, Madrid, Melbourne, New York and Tokyo 1994

Van Eck-Smit B L F, Van der Wall E E, Kuijper A F M, Zwinderman A H, Pauwels E K J: Immediate thallium-201 reinjection following stress imaging: a time-saving approach for detection of myocardial viability. J Nucl Med 34: 737-743, 1993

Van Rijk P P, Van Dongen A J: The position of nuclear medicine in Europe - the results of a European questionnaire. Tijdschr Nucl Geneeskd 20: 159-164, 1998

Vauramo E: An investigation into visualisation problems in radioisotope scanning. Åbo Akademi, Åbo 1970

Vauramo E, Carlsson C, Britton K, Jonsson R, Jönsson K and Åsard P-E: Version nr 3, EAL/COST B2: Accreditation in the field of Nuclear Medicine. Guidance on the interpretation of ISO/IEC Guide 25, Third Edition 1990

Volodin V, Souchkevitch G, Racoveanu N et. al. World health organization inter-laboratory comparison study in 12 countries on quality performance of nuclear medicine imaging devices. Eur J Nucl Med 10:193-197, 1985

Wittry M D, Juni J E, Royal H D, Heller G V, Port S C: Procedure guideline for equilibrium radionuclide ventriculography. J Nucl Med 38: 1658-1661, 1997

Woolfson R G, Neild G H: The true clinical significance of renography in nephro-urology. Eur J Nucl Med 24: 557-570, 1997

APPENDIX: ORIGINAL PUBLICATIONS