Scatter correction in hippuran clearance estimation with the modified Oberhausen technique

Karl Heinz Bohuslavizki,[1] Winfried Brenner,[1] Stephan Tinnemeyer,[1] Matthias Felber,[1] Malte Clausen,[2] Eberhard Henze[1]

[1] Clinic of Nuclear Medicine, Christian-Albrechts-University, Kiel, Germany
[2] Department of Nuclear Medicine, University Clinic Eppendorf, Hamburg, Germany

The modified Oberhausen technique is widely used in the estimation of hippuran clearance. However, when using a gamma camera the slope of the retention curve may be influenced by scattered photons from the kidneys. Therefore, the aim of this study was to quantify renal scatter and to elucidate the underlying factors. Scatter was measured in a seperate energy window in 47 patients with fast and in 31 patients with prolonged reno-vesical transport. An excellent correlation between renal clearance obtained with and without scatter correction was yielded (n = 76; r^2 = 0.993, SEE = 10.7 ml/min/1.73 m^2). In two patients only, we underestimated renal clearance by 43 and 47 % when scatter correction was omitted (see Figure 1). As underlying factors we determined obstruction and concomitant impaired renal function. In conclusion, in these patients an underestimation of renal clearance in renal function studies should be kept in mind.

Key words: metabolic clearance rate; iodohipporic acid; scattered, radiation; hippuran clearance, modified Oberhausen technique, scatter correction

Introduction

Renal function scintigraphy with iodine-123-hippuran is an established quantitative method in nuclear medicine.[1-3] The classical definition of renal clearance for the single shot-technique and falling plasma concentration of radioiodine-hippuran is total body loss (dm) of the tracer per time (dt) devided by the corresponding plasma concentration (C_{Pl}), according to equation 1.

$$Cl = \frac{\frac{dm}{dt}}{C_{Pl}} \qquad (1)$$

Correspondence to: Dr. Karl H. Bohuslavizki, Christian-Albrechts-University of Kiel Arnold-Heller-Str. 9, D.24105 Kiel, Germany, Tel.: +49 431 597-3076, Fax.: +49 431 597-3065.

UDC: 616.61.072.72

This approach is free of any assumption concerning compartment analysis, may be directly measured by diagnostic in nuclear medicine, and has become a clinically feasible method of reference.[3] The original method requires total body count detection with renal and urinary bladder shielding.[4, 5] For reasons of practicability this method was modified by using a gamma camera background region-of-interest.[6-9] The resulting time-activity-curve was assumed to be representative for the total body retention curve of the tracer. This assumption has not been confirmed by the original author and indeed, in a careful comparison proved to be not reliable enough for clinical patient care.[10] This may be due to scatter of renal count rate into the backround ROI which are in the same field of view of the gamma camera used. However, in routine patient management clearance estimation is not influenced, since the time-activity-curves of both renal and background ROI have a parallel time course in the time interval of interest from 12 to 24 min post injection.

On the other hand, in patients with obstuctive uropathy a time-dependent increase of count rate over both kidneys yields a non-parallel time course of the respective time-activity-curves. In consequence, scatter of the kidneys may artificially flatten the total body retention curve. This directly results in a falsely decreased radioiodine-hippuran clearance.

Therefore, the purpose of this study was to estimate and subsequently to compensate for any undesired effects of renal scatter on the background slope. Parts of the results have been published in brief recently.[11-13]

Materials and methods

Out of routine clinical patient care 78 patients were included consecutively. These patients were devided into two groups: 47 patients (20 female, 27 male, age: 48.5 ± 16.7 years) with normal or fast reno-vesical transport and 31 patients (10 female, 21 male, age: 49.4 ± 25.4 years) with prolonged reno-vesical transport. Renal scintigraphy was performed in all patients after a bolus injection of 40 to 80 MBq I-123-hippuran in a conventional manner. Serial images were acquired in a posterior view using a LFOV-gama-camera equipped with a LEAP-collimator (Gamma Diagnost Tomo, Philips, The Netherlands) up to 25 min p. i. The symmetric 10 % energy window was set on the photopeak of I-123, i. e. 144–176 keV. The clearance was derived according to equation 1 using the physiologic approach for clearance estimation, i. e. plasma concentration at 12 and 24 min p. i. and the slope of the camera background retention curve at the respective time were combined with the standard algorithm. The background ROI was positioned in the largest possible distance to the kidneys in the basal parts of the lungs.

In addition, during data acquisition a second energy window, set from 96 to 144 keV[14] was used to sample scatter information. Follwing standard data evaluation for renal clearance calculation, different fractions of the scatter images from 0 to 80 % were subtracted from the original photopeak of the background ROI.[7, 14-16] As a second method of scattter correction a constant fraction of 1 to 5 % of the activity of the renal ROIs was subtracted from the background ROI without measurement of scattered radiation.

In order to recognise both differences and both patient groups basing on scattered radiation and the success of the correction for scattered radiation, we introduced the slope S of the retention curve given by the logarithm of the retention value at 24 min (R_{24min}) devided by the retention value at 12 min (R_{12min}), as given in equation 2. These slope values of both patient groups are not directly comparable since they are dependent of the respective clearance values. Therefore, slope values were normalised with the individual clearance of the respective patient. When starting from a one compartment model,[17] the slope of the retention curve is a direct measure for the respective clearance. Thus, an index derived by dividing the slope and the clearance (Cl_i) should be constant. Any deviation of this index between both patient groups should, therefore, be due to scattered radiation.

$$S = \ln\left(\frac{R_{24\,\mathrm{min}}}{R_{12\,\mathrm{min}}}\right) \quad (2)$$

For reasons of practicability we normalised the terived index I according to equation 3 with a factor F as given in equation 4 in order to yield values near unity without any dimension.

$$I = \frac{S}{Cl} \cdot F \quad (3)$$

$$F = \frac{\sum_{i=1}^{78} Cl_i}{\sum_{i=1}^{78} \ln\left(\frac{R_{24\,\mathrm{min}}}{R_{12\,\mathrm{min}}}\right)_i} \quad (4)$$

Data are given as mean ± one standard deviation. Curve fitting was quantified by the linear regression coefficient, r and the standard error of the estimate (SEE). The difference between both patient groups was calculated with a two-tailed t-test according to Wilcoxon for unpaired data, with $p < 0.05$ considered to be statistical significant.[18]

Results

Scatter correction with measurements of a scattered fraction

The effect of an increasing correction of a scattered fraction in the background ROI on the correlation of the calculated index and modified hippuran clearance according to Oberhausen in both patient groups is given in Table 1. Without scatter correction the indices of both patient groups are different from 1

Table 1. Effect of subtraction of different fractions (F in %) from the scatter window of the photopeak from the background-ROI on the indices (I) in both patient groups with fast or normal reno-vesical transport (A: n = 47) and in patients with prolonged reno-vesical transport (B: n = 31) and its effect on the correlation (r^2, SEE) to the modified Oberhausen clearance. The latter was 358.0 ± 84.4 and 253.0 ± 156.8 ml/min/1.73 m^2 in group A and group B, respectively.

	Group A (n = 47)			Group B (n = 31)		
F	I	r^2	SEE	I	r^2	SEE
0	1.075 ± 0.354	0.183	0.323	0.886 ± 0.479	0.228	0.428
20	1.067 ± 0.335	0.223	0.299	0.898 ± 0.460	0.275	0.399
40	1.043 ± 0.289	0.354	0.235	0.935 ± 0.429	0.404	0.337
60	1.026 ± 0.265	0.444	0.200	0.961 ± 0.427	0.465	0.318
70	1.001 ± 0.239	0.564	0.159	0.998 ± 0.452	0.487	0.329
80	0.944 ± 0.265	0.407	0.206	1.085 ± 0.607	0.348	0.498

with figures of above 1 in group A and figures of below 1 in group B. In consequence, the correlation between index and clearance is low with r^2 = 0.183 in A and r^2 = 0.228 in group B. With an increasing subtracted scatter fraction F the difference in both groups diminishes. The indices are converging to 1. In consequence, the correlation between index and hippuran clearance becomes gradually closer. An optimal subtraction is yielded by subtracting 70 % of the scatter window from the photopeak window in the background ROI. Consequently, the indices are almost 1 with r^2 reaching a maximum and SEE reaching a minimum. With increasing subtraction of 80 % the correlation worsens again. This is due to an overcorrection.

Scatter corrrection without measurement of scattered radiation

The effect of different scatter corrrections without direct measurement of the scattered fraction on the corrrelation of index and clearance values in both patient groups is given in Table 2. Varying degrees of the photopeak of the renal ROIs ranging from 1 to 5 % were subtracted from the photopeak of the background ROI. Without any scatter correction the indices of both patient groups are different from unity again. With an increasing subtraction F this difference reaches a minimum when subtracting 3 % of the scatter window from the photopeak window. In consequence, the indices in both patient groups are converging at 1 with r^2 reaching a maximum and SEE reaching a minimum. Again, an increase of subtraction to 4 and 5 %, respectively, worsens the correlation of calculated index and hippuran clearance indicating overcorrectin.

Since the best correlation of the calculated index and hippuran clearance is reached with a subtraction of 70 % of the scattered window of the background ROI, corresponding to an optimum compensation for scattered radiation, this method is usede for the following an calculations.

Influence of scatter correction on renal clearance estimation

The scatter corrected clearance (Cl_{SC}) is shown versus the modified Oberhausen clearance (CL_{OH}) in Figure 1. As could be expected, the clearance was singificantly higher in patient with normal or fast reno-vesical transport (squares) as compared to patients with prolonged reno-vesical transport (circles): 358.0 ± 84.4 versus 253.0 ± 156.8 ml/min/1.73 m^2. Correlation equations and correlation parameters with respective renal clearance values with and without scatter correction are given in table 3 for differ-

Table 2. Effect of substraction of different fractions (F in %) from the photopeak of the kidney-ROI from the background-ROI on the indices (I) in both patient groups with fast or normal reno-vesical transport (A: n = 47) and in patients with prolonged reno-vesical transport (B: n = 31) and its effect on the correlation (r^2, SEE) to the modified Oberhausen clearance. The latter was 358.0 ± 84.4 and 253.0 ± 156.8 ml/min/1.73 m^2 in group A and group B, respectively.

	Group A (n = 47)			Group B (n = 31)		
F	I	r^2	SEE	I	r^2	SEE
0	1.063 ± 0.308	0.407	0.241	0.904 ± 0.296	0.089	0.294
1	1.041 ± 0.283	0.449	0.213	0.938 ± 0.265	0.187	0.249
2	1.015 ± 0.257	0.500	0.184	0.977 ± 0.251	0.350	0.211
3	0.986 ± 0.232	0.551	0.157	1.021 ± 0.287	0.446	0.222
4	0.951 ± 0.216	0.543	0.148	1.074 ± 0.436	0.332	0.371
5	0.909 ± 0.240	0.343	0.197	1.138 ± 0.855	0.174	0.809

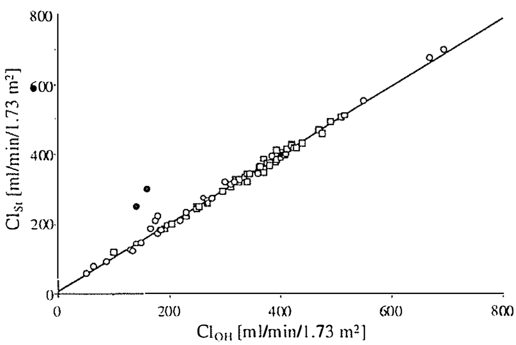

Figure 1. Scatter corrected (Cl_{SI}) versus modified Oberhausen clearance (Cl_{OH}) in ml/min/1.73 m^2 in 47 patients with normal or fast (squares) and 31 patients with prolonged (circles) reno-vesical transport. Note, two patients with obstructive uropathy and concomitant decreased renal fuction (filled circles) in whom renal function would have been underestimated without scatter correction by 43.5 and 46.7 % respectively. For correlation equation see Table 3.

ent patient groups. In 47 patients with normal or rast reno-vesical transport (Table 3, group A) an excellent correlation of clearance values with and without scatter correction was yielded.

estimated by 43.5 and 46.7 %, respectively.

Without these two patients (table 3, group B without 2) correlation of scatter corrected clearance and Oberhausen clearance was as goood as in group A (r^2 = 0,993; SEE: 13.5 ml/min/1.73 m^2).

Discussion

Pathophysiology

According to the definition of renal clearance (see equation 1) both parameters of the fraction, i. e. slope of the retention curve and plasma concentration of radioiodine-hippurane, can be measured directly. This physiologic and compartment-free approach was proposed by Oberhausen[4,5] using a whole body retention curve with renal and urinary bladder shielding. In recent time this method was modified by using a large-field-of-view gamma camera.[8] However, this implies that both the renal and the background ROI are in the same field-of-view of the gama camera used. Therefore, scattered radiation from the kidneys into the background ROI is implicitly a more pronounced problem when compared to a whole body counter as proposed by Oberhausen. In order to minimize this problem, the background ROI is positioned as far away from the kidney ROIs as possible.

Table 3. Correlation of modified Oberhausen clearance with (Cl_{SI}) and without (Cl_{OH}) optimal scatter correction (r^2, SEE in ml/min/1.73 m^2) in different patient groups with fast or normal reno-vesical transport (A: n = 47) and patients with prolonged reno-vesical transport (B: n=31), with and without these both patients with obstructive uropathy and concomitant decreased renal function.

Patients	n	Correlation equation	r^2	SEE
GroupA	47	$Cl_{SI} = 0.98 \cdot Cl_{OH} + 4.9$	0.990	8.3
Group B	31	$Cl_{SI} = 0.96 \cdot Cl_{OH} + 22.4$	0.956	32.7
Group A plus B	78	$Cl_{SI} = 0.95 \cdot Cl_{OH} + 19.6$	0.970	21.8
Group B without 2	29	$Cl_{SI} = 0.99 \cdot Cl_{OH} + 6.5$	0.993	13.5
Group A plus B without 2	76	$Cl_{SI} = 0.99 \cdot Cl_{OH} + 6.6$	0.993	10.7

In 31 patients with prolonged reno-vesical transport (Table 3, Group B) we found a very good correlation of the clearance values with and without scatter correction with al somewhat enlarged SEE (r^2 = 0.956; SEE = 32.7 ml/min) as well.

In two of 31 patients (Figure 1, filled circles) with prolonged reno-vesical transport and concomitant decreased renal function correlation between scatter corrected clearance and modified Oberhausen clearance was bad. The clearance values without scatter correction were 140 and 160 ml/min/1.73 m^2, respectively. On the other hand, when correcting for scattered radiation the clearance values were calculated as to 248 and 300 ml/min/1.73 m^2. Thus, without scatter correction clearance would have been under-

However, even with these assumptions we could show that approximately 3 % of the photopeak of the renal ROIs become effective within the background ROI. This correponds to a correction of scattered radiation in the background ROI of about 70 % of scattered radiation measured in an energy window from 96 to 144 keV.[14] These observations are in good agreement with data reported in the literature.[14-16]

In our patients we found a very good correlation of renal clearance calculated with and without scatter correction in all patients with fast or normal reno-vesical transport (see table 3, $r^2 = 0.990$). This holds true as well in 29 of 31 patients with a prolonged reno-vesical transport ($r^2 = 0.993$). However, in 2 patients with prolonged reno-vesical transport the hippuran clearance was underestimated by about 35 %. In these patients clearance values were not confirmed by an independent reference method.[19] Therefore, even clearance values after scatter correction may be underestimated. However, since we found very good correlation of the calculated clearance values with and without scatter correction ($r^2 = 0.993$) in the remaining 76 patients this may serve as an argument that we did not introduce artefacts with the scatter correction performed.

Two main factors could be shown to be important for the underestimation of renal clearance without scatter correction. The effect of a prolonged reno-vesical transport with a corresponding accumulation time of the time-activity-curves is easy to recognise since time-activity curves of renal and background ROIs are-non parallel. Moreover, the simultaneously decreased renal function is imperative for the underestimation of renal clearance as well. A scatter fraction of about 3 % of the photopeak of the renal ROI yields predominantly to an increase of late retention values. Therefore, a flat retention curve will be influenced more than a steep one. This implies that a reduced renal function will be influenced more than a normal renal function as could be expected from the so-called Oberhausen tables: a change of the fraction of retention values at 2 and 24 min p. i. (= E/D according to the Oberhausen tables) yields to less pronounced change in the slope of the retention curve in patients with normal renal function (E/D ≈ 0,5) as compared to patients with markedly decreased renal function (E/D ≈ 0.9).

Clinical applications

A markedly larger influence of scattered radiation has to be expected when positioning the background ROI in the near vicinity of the kidneys.[7] In patients with obstructive uropathy and decreased renal function hippuran clearance will be underestimated markedly. Therefore, in routine ptient management the background ROI will be positioned in the largest possible distance to the kidneys. However, this distance is limited by the field-of-view of the gamma camera used.

Since even under these conditions a scattered radiation fraction of about 3 % of the photopeak of the kidneys can be expected, this should be considered in patients with decreased renal function and obstructive uropathy. In these patients one should be aware of a marked underestimation of the clearance values calculated.

As could be shown in this paper the correction for scatter radiation can be performed *a posteriori* easily. However, this implies the acquisition of information related to scattered radiaton in a second energy window during routine renal scintigraphy. In daily patient management renal function scintigraphy can be corrected for scattered radiation if the calculated hippuran clearance and time-activity-curves of the kidneys suggest an underestimation of the hippuran clearance calculated.

Since the measured scatter fraction of the background ROI by the photopeak of the kidney ROIs of about 3 % is dependent on several factors, i. e. square of the distance of background ROI and kidney ROIs, body-weight this results in an enormous intra- and interindividual scatter. Therefore, its numeric value should be restricted to scientific work and, thus, should not be used for scatter correction in an individual patient.

Methodological considerations

In order to document an effective correction of scattered radiation we had to use a measure which is independent of the slope of the retention curve in an individual patient. Therefore, we started from the ordinates of the retention curves at 12 and 24 min as given by Oberhausen. These can be taken directly since the logarithm of this fraction is a direct measure for renal clerance when using a one-compartment model.[17] Normalising this slope by the individual renal clearance of the respective patient yields to an index which is independent of the individual renal function of the patient investigated. Since this index does not serve as a quantitative measure for the clearance itself and since we used this index simply to compare two patient-groups, the error introduced by a one-compartment model[17] can be neglected.

Thus, the differences of this index between two patient-groups indicate a lack of correlation of the slope of the retention curve and renal clearance. Since the only difference of these both patient-groups was the reno-vesical transport, difference of this index between both the groups is caused by different effective fractions of scattered radiation. Therefore, the index introduced is a measure for scattered radiation.

Although the numeric values of the index derived from the individual patient exhibit a relative large scatter, we could introduce a measure for the effect of scattered radiation by the division of our patients in two groups with different reno-vesical transport. This is supported by the fact that the indices go systematically in one direction with increasing correction of the scattered fraction. This could be shown statistically significant ($p < 0.05$) by a modified t-test calculated from the single values of correlation coefficients.[18]

Since the introduced index is of basic importance in order to measure the degree of scatter correction its behaviour shall be discussed in detail. First, the index used was normalised at 1 for better readability. In patients with normal or fast reno-vesical transport scatter from the kidneys in the background ROI is not effective. Therefore the indexs is near unity. On the other hand, in case of effective scattered radiation from the kidneys into the background ROI in patients with prolonged reno-vesical transport the retention curve will be flattened artificially. Therefore, the index is below unity. In case of an overcorrection of the scattered radiation the index will be above unity.

According to the definition of clearance (see equation 1) both parts of the fraction will change in the same direction with changing clearance values. Thus, clearance values can be estimated from measurements of the plasma concentration of the tracer[20-25] or from calculations of the slope of the time-activity-curve of the background ROI[26-28] as well. With the clearance estimation by measurement of the plasma concentration of the radiopharmaceutical at any time after injection there won't be any problem with scattered radiation from the kidneys since no time-activity-curve from the background ROI is used for clearance estimation.[20-22, 25] On the other hand, this method implies that there is a comparable distribution of the tracer in all body compartments between all patients investigated. Therefore, clearance estimation by single measurements of plasma concentrations are not valid in patients with non-homogenous distribution of the tracer in the respective compartments. The same holds in principle for clearance estimation from the slope of the retention curves alone.[26-29]

These limitations do not hold for the clearance estimation method according to Oberhausen since both parts of the clearance equation do change in the same sense. Therefore, even if in an individual patient tracer distribution in the different compartments of the body vary numeric values of radioiodine hippuran clearance will be calculated correctly. Moreover, it was shown, that the background ROI used with a modified Oberhausen method, is representative for the background ROI of the partly shielded whole-body configuration.[8]

Conclusions

Scattered radiation yields to an underestimation of the calculated radioiodine hippuran clearance using the modified Oberhausen method in a few patients only. However, this is of importance in patients with obstructive uropathy and concomitant decreased renal function. The effective scattered radiation should be minimised *a priory* by the maximum possible distance of the background ROI with respect to the kidney ROIs. Scatter correction can be obtained easily *a posteriori* by using and additional energy window collecting scatter data during the acquisition of renal function scintigraphy.

Acknowledgement

We thank A. Bauer, R. Bradtke, C. Fock, I. Hamann, W. Latendorf, S. Ossowski, M. Reymann and E. Schmidt for perfect technical assistance.

References

1. Blaufox MD, Fine E, Lee HB, Schar S. The role of nuclear medicine in clinical urology and nephrology. *J Nucl Med 1984*, **25**: 619–25.
2. Oberhausen E. Nuklearmedizinische Methoden in der Nephro-Urologie. *Münch Med Wschr* 1983; **125**: 465–7.
3. Oberhausen E, May P. Nuklearmedizinische Untersuchungen. In: Alken CE, Staehler W eds. *Klinische Urologie*. Stuttgart: Thieme, 1973: 76–92.
4. Oberhausen E. Bestimmung der Nierenclearance mit dem Ganzkörperzähler. In: Höfer R ed. *Nierenclearance*. Gelbe Reihe der Farbwerke Hoechst, 1968: 1–19.
5. Oberhausen E. Nuklearmedizinische Untersuchungen. *Radiologe* 1981; **21**: 548–52.
6. Fine EJ, Axelrod M, Gorkin J, Saleemi K, Blaufox MD. Measurement of effective renal plasma flow a comparison of methods. *J. Nucl Med* 1987; **28**: 1393–1400.

7. Kotzerke J, Wallburger M, Gettner U, Burchert W, Hundeshagen H. Vergleich zweier Algorithmen zur Bestimmung der renalen Ganzkörper-Clearance nach simultaner Akquisition mit dem teilabgeschirmten Ganzkörperzähler und der Gammakamera. *Nuc Med* 1990; **29**: 101–8.

8. Rohloff R, Hast B, Leisner B, Heinze HG. Bestimmung der ^{131}J-Hippuran-Clearance im Rahmen der Kamerafunktionsshzintigraphie der Nieren nach vereinfachten Modifikationen der Methode von Oberhausen. *Nucl Med* 1975; **13**: 303–20.

9. Sonntag A. Einfache nuklearmedizinische Nierenclearancemethoden im Vergleich. *Nucl Med* 1984; **23**: 155–60.

10. Buvat I, Benali H., Todd-Pokropek A, Di Paola R. Scatter correction in scintigraphy the state of the art. *Eur J Nucl Med* 1994; **21**: 675–94.

11. Clausen M, Bohuslavizki KH, Felber M, Schramm M, Wolf H, Brenner W, Eberhardt JU, Stauch C, Zimmermann JS, Henze E. Streustrahlenkorrektur der Retentionskurve bei der Nierenfunktionsszintigraphie mit einem Compton-Energiefenster. *Nucl Med* 1994; **33**: A26.

12. Clausen M, Bohuslavizki KH, Felber M, Schramm M, Wolf H, Czapp W, Brenner W, Eberhardt JU, Stauch C, Zimmermann JS, Henze E. Scatter correction in renal studies with radioiodinehippuran. In: Bergmann H, Sinzinger H eds. *Radioactive isotopes in clinical medicine and resarch.* Basel: Birkhäuser, 1995: 241–5.

13. Felber M, Clausen M, Schramm M, Wolf H, Bohuslavizki KH, Brenner W, Eberhardt JU, Stauch C, Henze E. Beeinflussung der Retentionskurve aus einer Hintergrund-ROI durch die Nierenaktivität bei der Funktionsszintigraphie. *Nucl Med* 1994; **33**: A59.

14. Jasszczak RJ, Greer KL, Floyd CE, Harris CC, Coleman RE. Improved SPECT quantification using compensation for scattered photons. *J Nucl Med* 1984; **25**: 893–900.

15. Gilardi MC, Bettinardi V, Todd-Pokropek A, Milanesi L, Fazio F. Assessment and comparision of three scatter correction techniques in single photon emission computed tomography. *J Nucl Med* 1988; **29**: 1971–9.

16. Ljungberg M, King MA, Hademenos J, Strand SE. Comparison of four scatter correction methods using monte carlo simulated source distributions. *J. Nucl Med* 1984; **35**: 143–51.

17. Rösler H. Die Bestimmung der o-^{131}J. Hippursäure Total-Clearance als Grundlage einer quantitativen Radionephrographie. *Dtsch Med Wschr* 1976; **92**: 881–5.

18. Sachs L. *Applied statistics A handbook of tecniques.* Berlin, Heidelberg, New York: Springer, 1984.

19. Sapirstein LA, Vidt DG, Mandel MJ, Hanusek MJ. Volumes of distribution and clearances of injected creatinine in the dog. *Am J Physiol* 1955; **181**: 330–5.

20. Piepenburg R, Bockisch A, Anfreas A, Düber C, Kann P, Maier G, Hahn K. ^{99m}Tc-MAG3-Nierenfunktionsszintigraphie ohne und mit Captopril zur Diagnostik der renovaskulären Hypertonie. *Fortschr Röntgenstr* 1993; **159**: 150–7.

21. Schaub T, Schweden F, Witsch U, El-Damanhoury H, Schild H, Thelen M. Computertomographie nach extrakorporaler Stoßwellenlithotripsie (ESWL) der Nieren Teil III Prospektive CT-Untersuchungen bei 105 Patienten und Drei-Jahres-Kontrolle bei 23 Patienten mit CT und seitengetrente ^{99m}Tc-MAG3-Clearance. *Fortschr Röntgenstr* 1993, **158**: 121–6.

22. Schaub T, Witsch U, El-Damanhoury H, Nägele-Wöhrle B, Hahn K. ^{99m}Technetium-Mercaptoacetyltriglycin (MAG3) zum Nchweis von Nierenveränderungen nach extrakorporaler Stoßwellenlithotripsie Eine prospektive Untersuchung bei 117 Patienten. *Fortschr Röntgenstr* 1992; **157**: 338–43.

23. Tauxe EN, Dubovsky EV, Kidd T, Diaz F, Smith LR. New formulas for the calculation of effective renal plasma flow. *Eur J Nucl Med* 1982; **7**: 51–4.

24. Tauxe EN, Maher FT, Taylor WF. Effective renal plasma flow estimation from theoretical volumes of distribution of intravenously injected ^{131}I-orthoiodo hippurate. *Mayo Clin Proc* 1971; **46**: 524–31.

25. Willich N, Heidenreich P, Renner D. Vereinfachte Verfahren zur Nierenclearancebestimmung Ergebnisvergleich der ^{51}Cr-EDTA-Slope-Clearance, J-Hippuranclearance, endogene Kreatininclearance. *Fortschr Röntgenstr* 1983; **138**: 553–7.

26. Sonntag A. MAG3-Clearance methodischer Aufwand und Ergebnisqualität. *Nucl Med* 1994; **33**: 68.

27. Winkler K, Fischer M, Buchinger HD, Hengst W. Vereinfachte Methode zur Bestimmung der Nierencleasrance. *Nuc Compact* 1979; **10**: 235–8.

28. Winter CC. *Radioisotope renography.* Baltimore: Williams & Wilkins, 1963.

29. Junges R. Der Influß der Meßmethode auf die Bedeutung der Nierenclearance. *Fortschr Röntgenstr* 1985; **142**: 212–4.