
New Automated Physical Phantom for Renography

Jari O. Heikkinen, PhD

Department of Nuclear Medicine, Etelä-Savo Hospital District, Mikkeli Central Hospital, Mikkeli, Finland

Physical phantoms have been used to test the diagnostic proficiency of nuclear medicine professionals and the accuracy of their equipment in external quality assurance surveys. No dynamic renal phantoms are commercially available. A new renal phantom, presented in this paper, was constructed and patented in the United States. **Methods:** The organs to be simulated by the phantom were in the form of containers filled with radioactive solution, and the device further comprised movable steel and lead plates between the containers and the γ -camera. The detectable radiation was regulated in accordance with automated computer-controlled step motors to move the attenuators to simulate a given patient situation. The reproducibility of the phantom measurements was defined as a coefficient of variation. Four different kidney-function simulations were repeated 3 times, and 6 parameters were compared. **Results:** The average root mean square deviation of the coefficient of variation was 6.7% for the perfusion integral, 1.3% for time to reach the maximum activity, 19.7% for mean transit time, 3.3% for function (Patlak [%]), 1.0% for outflow index (%), and 6.5% for time to reach the half-activity from maximum. **Conclusion:** With this phantom, the true values of most parameters measured are well known; it closely approaches true extraction, washout, and attenuation properties and curves, and the images produced are similar to those of patient studies. Compared with the first manual version, this new automated phantom is easy to use. Any desired clinical situation can be programmed. It is a promising tool for quality assurance and calibration of renography.

Key Words: phantom; renography; γ -camera; radionuclide imaging

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The availability of different radiopharmaceuticals, multiple quantitative parameters, and variable acquisition and processing protocols makes renal imaging a complex subject (1). Quantitative functional parameters assessed by different institutions are not always comparable. Standardization of nuclear medicine procedures is essential, and the entire diagnostic imaging chain needs to routinely be eval-

uated and developed. International consensus reports (2) can and should be used as a gold standard.

With the need for quality control in nuclear medicine, the need for correct use of instrumentation and objective comparisons with interlaboratory clinical studies is evident. Most parts of the imaging chain have to be considered in multicenter comparisons. Computer-simulated data (i.e., hybrid phantoms) (3,4) are usually distributed to nuclear medicine departments and analyzed with different programs. Analysis methods, printouts, and reporting can be compared between departments. However, the effect of 2 important parts of the imaging chain remain unknown: the acquisition protocol and the facility used. Physical phantoms can take them into account.

Since 1993, 6 external quality assurance surveys of nuclear medicine imaging have been arranged in Finland (5). The main purpose of the surveys has been similar to that of the Society of Nuclear Medicine Proficiency Testing Program. Physical phantoms were used to test the diagnostic proficiency of nuclear medicine professionals and the accuracy of their equipment. Phantoms were commercially available for most of those studies, except for renography. The first version of the renal phantom was operated manually and tested in 19 nuclear medicine laboratories (6,7). However, human error was possible because 2 people were connected to the phantom during the simulation.

The phantom was further developed with the help of the Foundation for Finnish Inventions. The new version was automated with computer-controlled step motors. The function and reproducibility of the new phantom were evaluated.

MATERIALS AND METHODS

The Structure of the Phantom

Figure 1A is a schematic presentation of the phantom. The phantom has been patented in the United States (8). The basic structure is similar to that of the first version, published earlier (6). The functional organs simulated by the phantom were the heart, kidneys, and bladder. The simulated organs were in the form of plastic containers filled with radioactive solution, and the device further comprised movable steel plates between the kidney containers and the γ -camera to isolate radiation in the containers from the camera. The detected radiation was used to simulate the function of the kidneys. The number of steel plates between the container and the γ -camera simulated extraction and washout of the kidneys (Fig. 1A). This prototype had 36 plates for each

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For correspondence or reprints contact: Jari O. Heikkinen, PhD, Department of Nuclear Medicine, Etelä-Savo Hospital District, Mikkeli Central Hospital, FIN-50100 Mikkeli, Finland.
E-mail: jari.heikkinen@esshp.fi

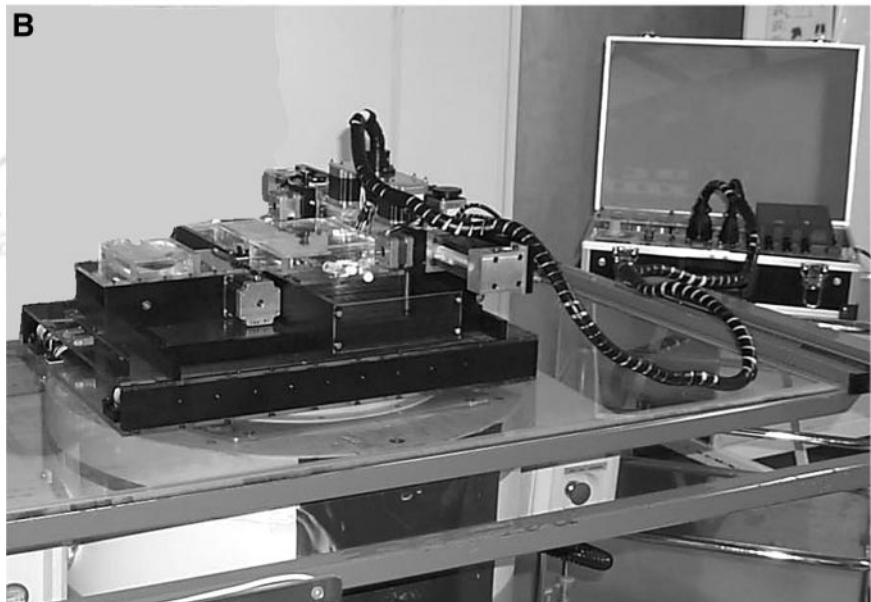
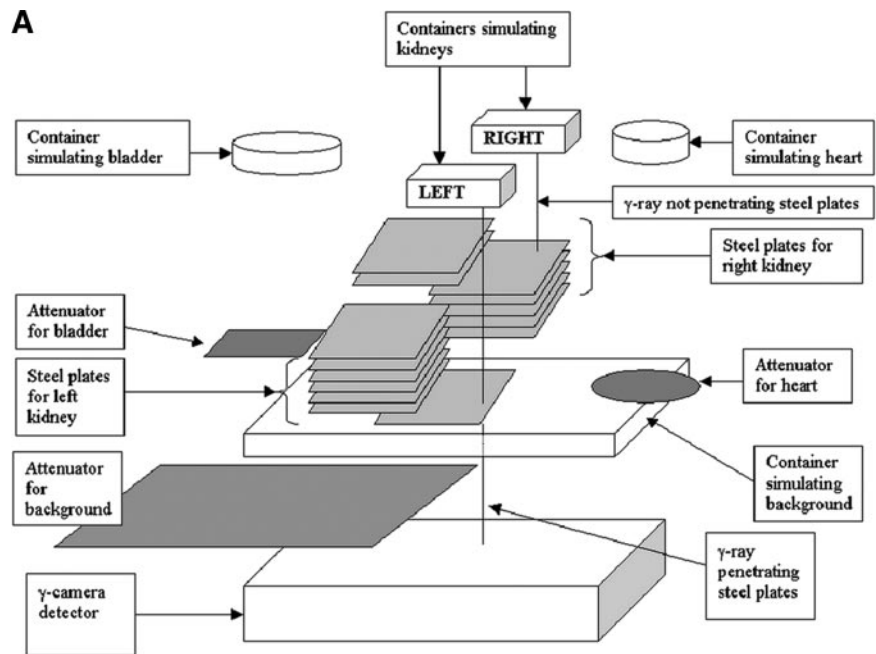


FIGURE 1. (A) A simplified schematic presentation of the phantom. Under the kidney containers are 7 steel plates. Six of the 7 plates have been moved away from the space between the γ -camera detector and the left kidney container, and 2 of the 7 have been moved under the right kidney container. (B) A photograph of the phantom on a γ -camera, beside the control unit on a table.

kidney. Heart functioning was simulated using a rotating lead plate between the heart container and the γ -camera. The radial attenuation properties of the lead plate varied. The lead plate under the bladder container was moved caudally to mimic filling of the bladder. The nonfunctional organs simulated by the phantom were the spleen, liver, and soft tissues. Those containers also were filled with radioactive solution. All containers and step motors were fixed in a compact package that could be positioned on the γ -camera. In addition, a control unit was electrically connected to that combination (Fig. 1B). Inside the control unit were microprogrammable logic controllers (Simatic, S7-200; Siemens AG) that regulated the movement of the motors of the steel and lead plates.

Experimental Measurements

A γ -camera (Orbiter; Siemens) equipped with an all-purpose collimator was used. First, all containers were filled with a solution

of technetium and water. Volumes and activities in various containers are presented in Table 1. Then, the phantom was positioned on the γ -camera (Fig. 1B). The preprogrammed simulation was started by pressing the start button of the control unit. The same phantom simulations as conducted with the first manual phantom (6) were repeated 3 times. Containers were refilled for each simulation. γ -Camera acquisition was started immediately. The first 30 images were acquired at 2-s intervals. Subsequently, 90 images were acquired at 20-s intervals. Data were analyzed with the Hermes program (Nuclear Diagnostics AB). Root mean square averages of the coefficient of variation (RMS CV) (9) for the repeated measurements were calculated for 6 parameters: relative perfusion (integral), time to maximum counts, mean transit time (MTT), relative function (Patlak [%]), outflow index (%), and emptying half-time.

TABLE 1

Volumes and Activities of Phantom Containers Simulating 111-MBq (MAG3) Patient Dose

Container	Curve	Volume (mL)	Activity (MBq)
Left kidney	1 and 2	180	59.5
	3 and 4	50	21.0
Right kidney	1 and 2	180	59.5
	3 and 4	30	10.5
Background		590	7.0
Heart		11	3.5
Liver		100	2.5
Bladder		30	28.0

RESULTS

A set of obtained image series and curves is presented in Figure 2. The phantom images appear similar to images of a patient. Most regions of interest can be drawn as in clinical routine. Also, bladder activity can be seen in the last few images (Fig. 2E).

The reproducibility of the parameters is presented in Table 2. For comparison, the results obtained with the first version of the phantom (6) are presented in the second column (Table 2). Results were in line with those of the old phantom. The best results were obtained with outflow index (%), time to maximum count, and relative function (Patlak [%]).

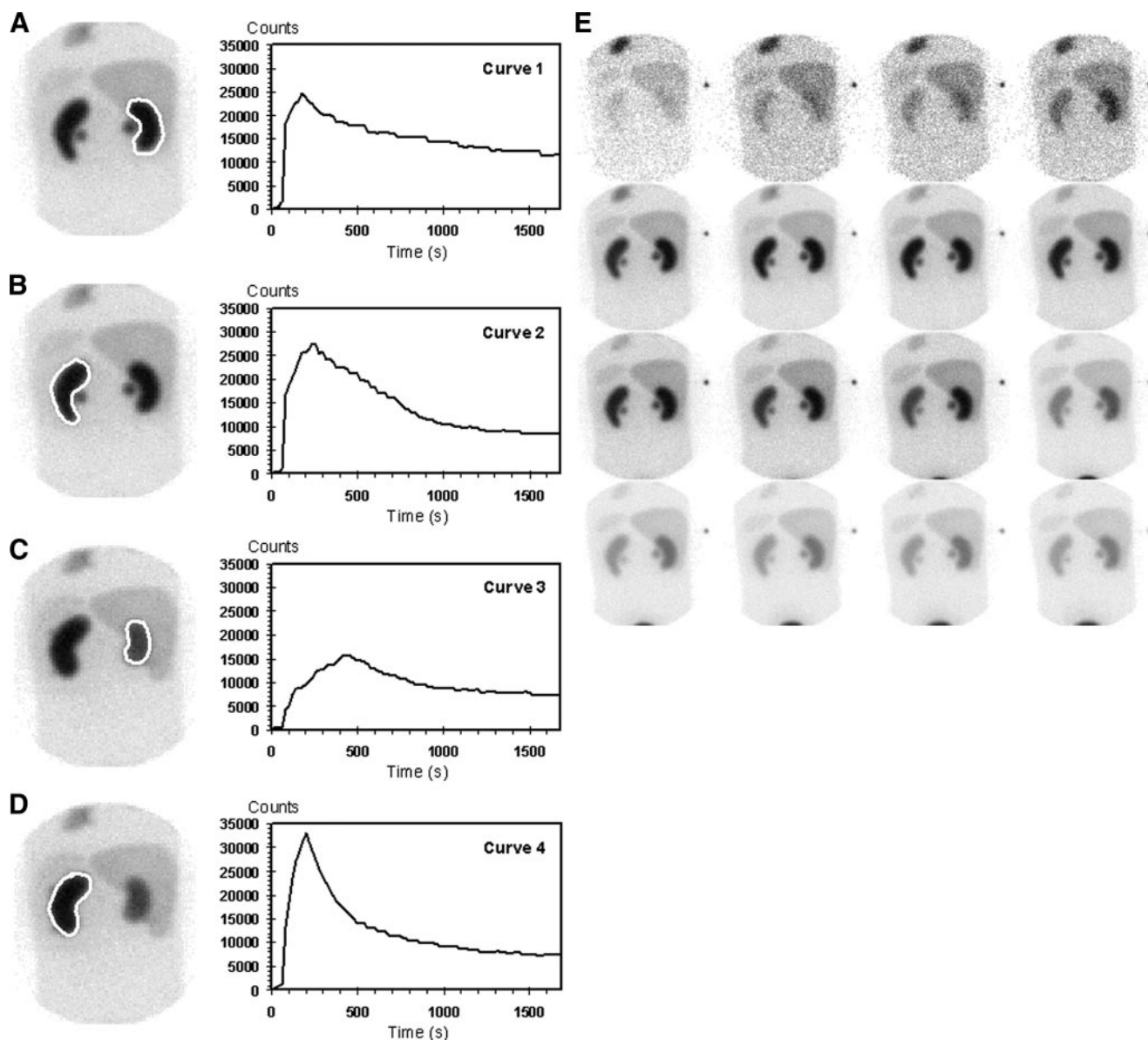


FIGURE 2. (A–D) The simulated 4 curves and corresponding regions of interest (white outlines drawn around the kidney areas). (E) An example of the image series of a simulation. Each image is summed over a period of 1 min 45 s. The series goes from left to right, starting at the upper left corner.

TABLE 2
Average RMS CV for Analyzed Parameters

Parameters by the HERMES program	Average RMS CV (%)	Average RMS CV (%) of the old phantom	Curve 1 CV (%)	Curve 2 CV (%)	Curve 3 CV (%)	Curve 4 CV (%)
Relative perfusion (integral)	6.7	6.3	3.3	3.7	12.4	1.7
Time to maximum counts	1.3	1.5	0.0	0.0	2.5	0.0
MTT	19.7	12.4	39.3	1.8	0.9	0.0
Relative function (Patlak [%])	3.3	2.5	3.8	4.6	2.6	0.7
Outflow index (%)	1.0	1.2	0.7	0.6	1.8	0.0
Emptying half-time	6.5	4.3	9.9	0.0	8.3	0.0

Only the reproducibility of the MTT was unsatisfactorily low. This reproducibility was also low with the old phantom. Curve 1 had an RMS CV of 39.3%, whereas curves 2, 3, and 4 had values of 1.8%, 0.9%, and 0.0%, respectively. Similar results were seen in the relative perfusion value for curve 3. Average RMS CV was the second highest but acceptable. The emptying half-time result was the third highest and lower than with the old phantom. The value was high in curves 1 and 3 but was zero in curves 2 and 4.

DISCUSSION

Compared with the first manual version, this new phantom is easy to use. Most of the moving parts are controlled using computerized step motors. Clinical situations such as obstruction, nephropathy or fibrosis (i.e., decreased filling or washout of the kidneys), hydronephrosis, renovascular hypertension, and normal renal function can be programmed by the personal computer and copied to the control unit. The user has only to select the desired program and press the start button. Operation of the manual version of the phantom required 2 people, introducing the possibility of human error. When the users were experienced, these errors were, however, acceptable (Table 2). With this new automated phantom, sources of human error have been significantly reduced. Carefully following a set of instructions, all users can easily produce identical simulations, even with no previous experience using the phantom. This new phantom, or a similar construction, can easily be used for quality assurance in a program such as the Society of Nuclear Medicine Proficiency Testing Program.

The materials and shapes in the phantom were chosen according to experience with the first version. The containers were plastic, and the attenuating materials were steel and lead. Simulation of the function of the dilated collection system (i.e., ureters and pools) is still manual in this prototype. The phantom is compromised in that the renal cortex and the collecting system are not simulated separately. Furthermore, this version does not yet solve the simulation of background function. The liver and spleen were not dynamic. Further development of the phantom may solve these problems by, for example, increasing the steel plates and step motors under other containers.

Zubovskii et al. (10) and Karagöz et al. (11) have developed renography phantoms based on the flow of the radioactive liquid and permeable membranes. These investigators did not report the reproducibility of their phantom simulations. The use of physical phantoms based on radioactive liquid flow may create difficulty with defining the true values of the parameters being measured and the true shapes and locations of the organs. Extra measuring systems for the flow of radioactive solution inside simulated organs are probably required to ensure reproducibility. In the phantom presented here, the dynamics of the simulated organs depend on mechanical movements of the attenuators. All parameters except MTT showed good reproducibility. The situation was the same with the first version of the phantom. The parameters depend on multiple factors, such as the algorithm used. However, analysis methods for MTT have not yet been standardized (2), and Houston et al. have found similar results with a software phantom (12). They had 10 patient datasets. MTT values varied greatly with 3 datasets.

Hybrid and software phantoms are useful but cannot take into account the acquisition system, that is, the γ -camera and protocols used. When physical phantoms are based on mechanical movements of the steel plates, the true values of the majority of the parameters measured are well known and the images are similar to those of patient studies. In this phantom, a computer program can change the dynamics to simulate all possible clinical situations. Until now, a physical phantom has not been physiologic. This is the first phantom to come close to true extraction, washout, and attenuation properties.

The patent has recently been accepted in the United States. Various kinds of kidney phantoms—from a simple version to a complicated whole-body version as described in this paper—can be developed. We hope that the phantom will be commercially available within the next few years. In the future, there will be a new family of dynamic phantoms in the field of nuclear medicine.

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