Tests of down-scatter correction in simultaneously acquired ^{99m}Tc perfusion and ^{81m}Kr ventilation scans

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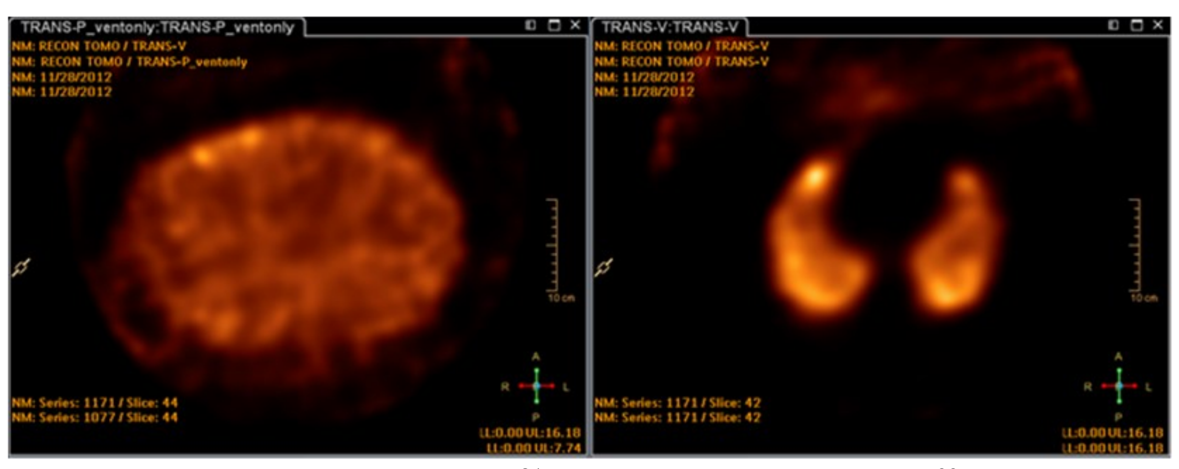
Introduction:

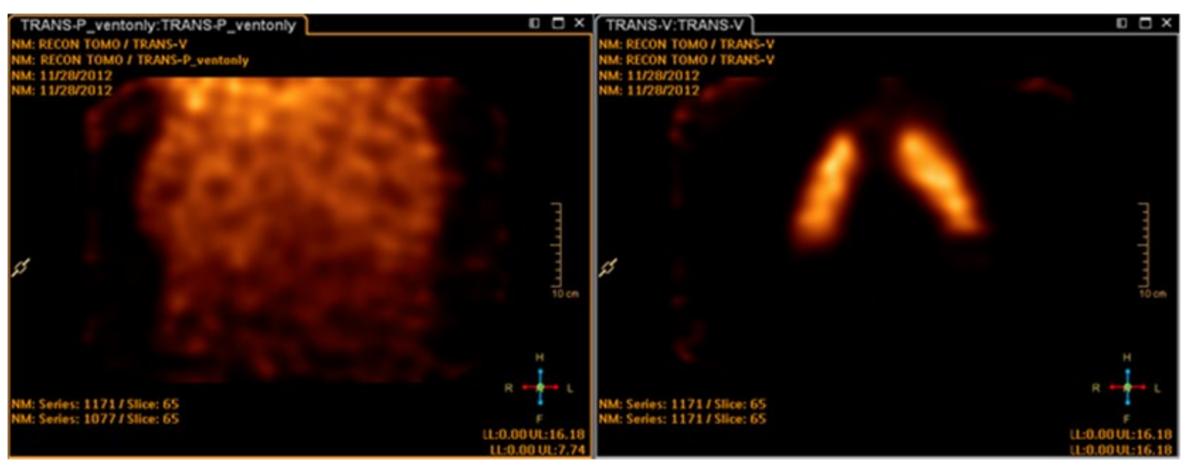
Lung scans are basic nuclear medicine studies, typically used to diagnose lung embolism by comparing ventilation and perfusion scintigraphies. A gamma camera acquires the ventilation studies of a radioactive gas or aerosol inhaled by a patient, and the camera acquires the perfusion studies of ^{99m}Technetium macro aggregated albumin injected in the patient's blood. There are several possible gasses or aerosols for ventilation scintigraphy, but ^{81m}Krypton is usually considered the golden standard.

Due to the higher gamma energy of ^{81m}Kr compared to ^{99m}Tc, ventilation and perfusion scans can be acquired simultaneously, which saves time and allows perfect image registration. Unfortunately, down-scatter of ^{81m}Kr distorts the perfusion studies in the ^{99m}Tc energy window. ^{81m}Kr gas in the patient's lungs emits photons at 190.5 keV, and some of these interact with tissue, scatter, change direction and lose energy. A considerable fraction (30 - 40%) of these down-scattered photons is acquired in the ^{99m}Tc energy window at 140 keV, blurring the perfusion images. A widely used method to solve this problem is to subtract a fraction of the ventilation studies from the perfusion studies, as descripted in several scientific articles. However, we suspect this to be an inadequate procedure that may even lead to further degradation of the perfusion scans.

^{81m}Kr gas is well-defined in the patient's lungs, but we expect photons to be scattered mostly in the surrounding tissue. In that case, a scintigraphy of the down-scattered photons will not simply be a fraction of the ventilation scintigraphy, and a correction based on subtraction of this study will not be suitable. As a preliminary verification of this theory, we added a ^{99m}Tc energy window to a ventilation SPECT of a patient with no ^{99m}Tc present, and the results were as expected. The first images below show two correlated transverse views and the next images show two correlated coronal views. On the left side, there are views from the ^{99m}Tc energy window and on the right side views from the ^{81m}Kr energy window .



Transverse views after inhalation of ^{81m}Kr gas, without injection of ^{99m}Tc.
Left image: ^{99m}Tc energy window (140.0 keV ± 10%, down-scatter of ^{81m}Kr).
Right image: ^{81m}Kr energy window (190.5 keV ± 10%).



Coronal views after inhalation of ^{81m}Kr gas, without injection of ^{99m}Tc.
Left image: ^{99m}Tc energy window (140.0 keV ± 10%, down-scatter of ^{81m}Kr).
Right image: ^{81m}Kr energy window (190.5 keV ± 10%).

The views to the right show images of well-defined ^{81m}Kr in the lungs, while the views to the left show the contour of the patient. This supports our theory, that the views of the down-scattered photons are not simply fractions of the ventilation studies.

Methods:

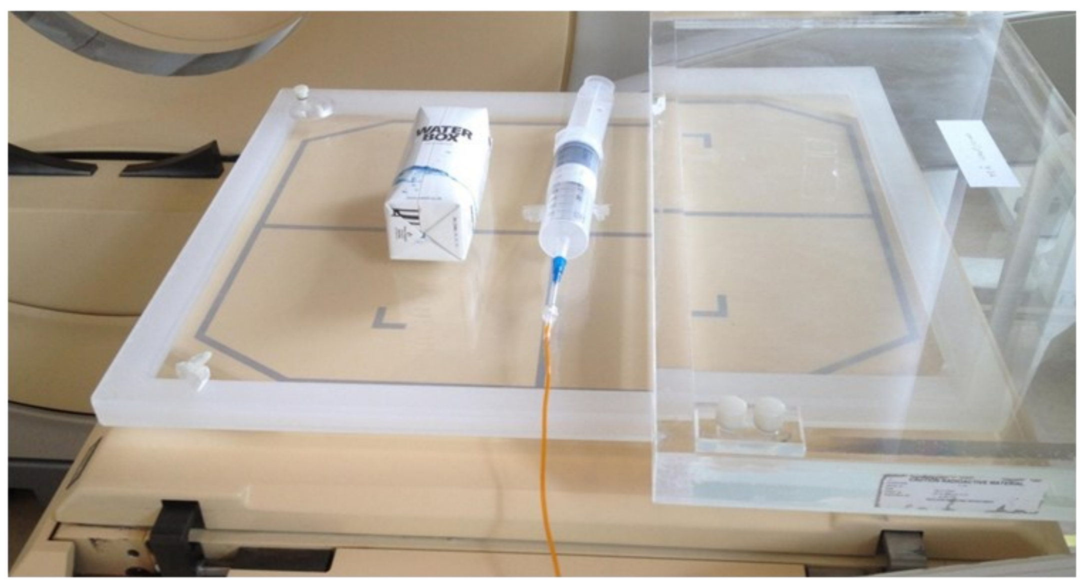
The experiments with the homemade phantoms were performed with ^{81m}Kr . The gamma detector was placed horizontally and the syringe, the cardboard water box and the water phantom were placed on the top of the detector. The syringe was connected with the ^{81m}Kr source, which also was connected to an oxygen pump. The camera was setup to use six energy windows: the energies of ^{81m}Kr and ^{99m}Tc along with three windows in between and one window above ^{81m}Kr to test for up scatter. The energy windows are listed below with middle energies along with the widths of the windows.

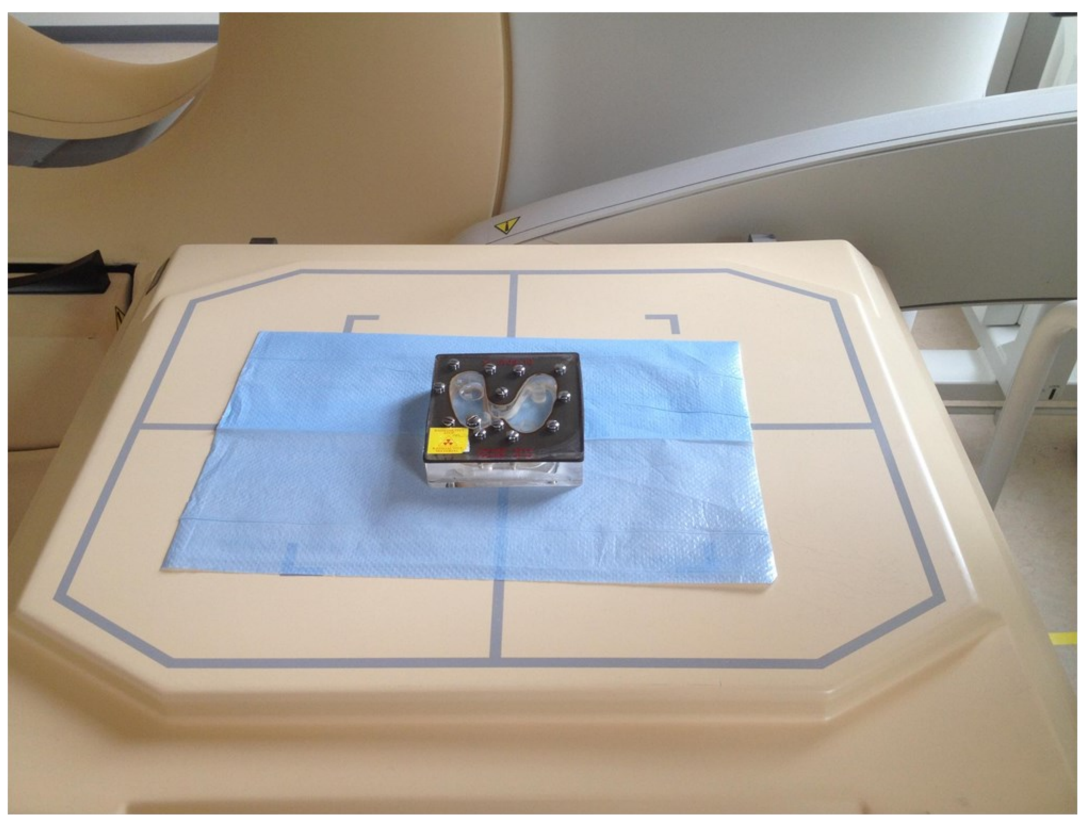
1. 140.0 keV ± 10%:	126.0 - 154.0 keV Normal ^{99m}Tc window
2. 190.5 keV ± 10%:	171.5 - 209.6 keV Normal ^{81m}Kr window
3. 163.0 keV ± 5%:	154.9 - 171.2 keV Full interval between ^{99m}Tc and ^{81m}Kr
4. 159.0 keV ± 2.5 %:	155.0 - 163.0 keV Lower half of window 3
5. 168.0 keV ± 2.5 %:	163.8 - 172.2 keV Upper half of window 3
6. 221.0 keV ± 5 %:	210.0 - 232.1 keV window above ^{81m}Kr.

Experimental setup:

The syringe was held in place with tape and was aligned with the center line of the collimator, with the water boxes placed next to it. Before the acquisition was started, the syringe (or latex glove) was filled with ^{81m}Kr. The measurements were done within 60 seconds with the source disconnected due to possible leakage. Five acquisitions were made with the water phantom setups: one with the water phantoms close to the syringe, next at 2 cm apart, then at 5 cm apart and at 10 cm apart. Afterwards the 2.5 cm thick water phantom was placed between the syringe and the camera, and we acquired an image with the boxes at a distance of 5 cm. Furthermore one recording was made with the water boxes at 2 cm distance to the syringe with the energy windows below ^{99m}Tc. Two images were made with a latex glove as a container: one without the water boxes and one with the water boxes.

Three measurements were performed with a ^{99m}Tc phantom: The first one with the ^{99m}Tc phantom alone, the second one with the water boxes at a distance of 2 cm and the last one without the water boxes, but with a 2.5 water phantom under ^{99m}Tc phantom. Furthermore the measurement with the two energy windows below ^{99m}Tc was made.



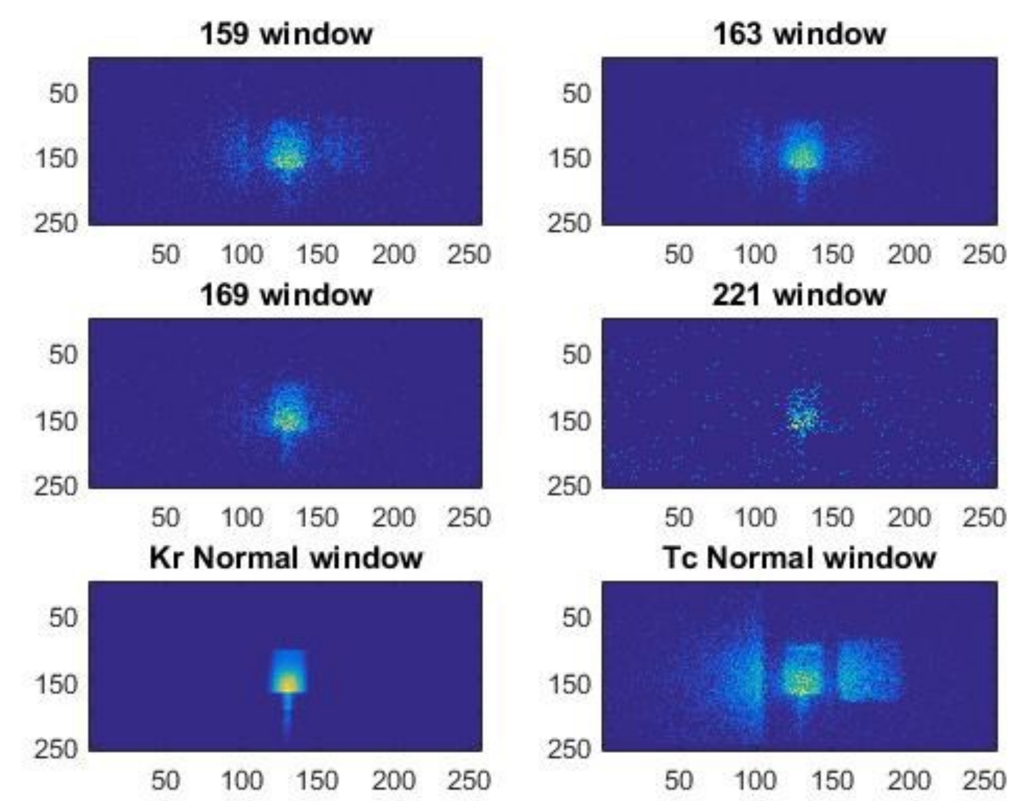


Results:

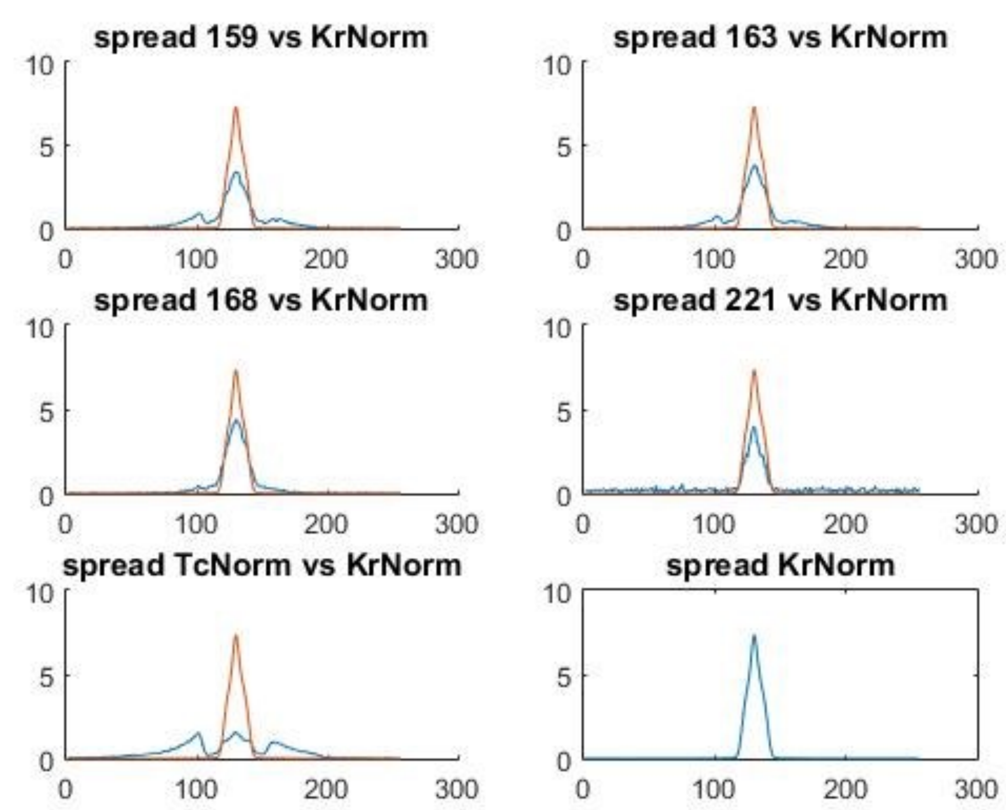
The first six images shown below are the recordings at the distance of 2 cm between the syringe and the water phantoms with the background subtracted. The image is scaled against the maximum and minimum values, which means that it is not possible to compare the intensity in each pixel based on the visual image. In the images the water cardboard box is on the right side of the syringe and the larger water phantom on the left. The numbers refer to the different energy intervals, with ^{81m}Kr Normal centered around 190.5 keV and ^{99m}Tc Normal around 140 keV. The solid items and water are visible, while almost no photons are scattered in the air.

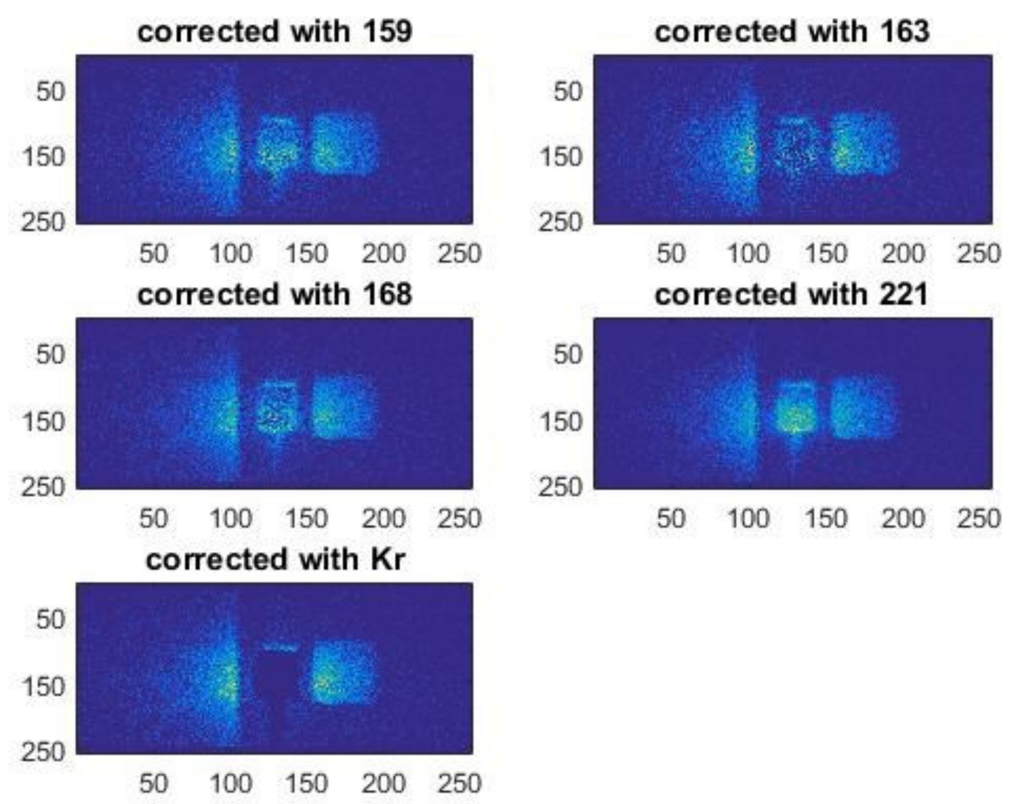
The following six images are the previous images collapsed along the vertical axis and rescaled to a percentage of the total number of counts in the original image. These images show the horizontal spread of the counts recorded. The windows have been compared to the spread from the ^{81m}Kr energy window.

The last six images are corrections of the images from the ^{99m}Tc energy window. The corrections are made with the images from the energy window 159 keV and compared with the correction made with ^{81m}Kr energy window. The correction could have been made with the 163 keV energy window since this covers the 159 keV window as well. The top half



of the 163 keV energy window does not add much information, which is not already covered in the lower half, thus the 159 keV interval was chosen. The fraction of ^{81m}Kr was 1/30, since this value removed most of the noise from the ^{99m}Tc energy window images without over correcting.





Conclusion:

The purpose of this project was to test the correction of down-scatter from ^{81m}Kr into the ^{99m}Tc energy interval. The results show that the often used correction, in which a fraction of the ^{81m}Kr scan is subtracted from the ^{99m}Tc scan, does not yield much improvement in this case, since the photons from ^{81m}Kr and the Compton scatter are emitted from different areas. It may even lead to a decreased quality of the perfusion scintigraphy. An alternative method was explored, and it seems to be plausible, but the viability needs further research, including tests on patient images.

If the quality of perfusion scintigraphies is unacceptable due to down-scatter of ^{81m}Kr, the best and easiest solution is not to make the two scintigraphies simultaneously. Due to the short half-life of ^{81m}Kr (13 seconds), the disadvantages are relatively small. On the other hand, SPECT is more and more commonly used as a part of lung scans, leading to a greater demand for simultaneously acquired ventilation and perfusion scintigraphies. Therefore, we expect to search for further improvements of the tested down-scatter correction procedures.

References:

[1] Y. Sando, T. Inoue2, R. Nagai, K. Endo. Ventilation/perfusion ratios and simultaneous dual-radionuclide single-photon emission tomography with krypton-81m and technetium-99m macro aggregated albumin. *Eur J Nucl Med* 1997; 10: 1237-1244.

[2] N.H. Strickland, J.M.B. Hughes, D.A. Hart, M.J. Myers, J.P. Lavender. Cause of Regional Ventilation-Perfusion Mismatching in Patients with Idiopathic Pulmonary Fibrosis: A Combined CT and Scintigraphic Study. *AJR* 1993; 161: 719-725.