Java-Based Plugin for Renal Depth Measurement

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Abstract*–This work presents an ImageJ plugin that was developed to measure the skin-to-kidney distance on planar lateral scintilographic images for academic research and clinical environment in Nuclear Medicine. The software was written in JAVA, has an open source code, is cross-plataform and named Renal Depth Measurement (RDM). Validation tests were performed in lateral images simulated with SimSET code, using five anthropomorphic GSF voxel phantoms. The quantitative analysis was compared with the empirical renal depth formula, developed by Raynaud. The depth measurements using the RDM plugin showed that the errors compared with the true renal depth are around -18% and 10% for the interactive delimitation method and around -7% and 10% for automatic method. When compared with Raynaud formula, there is a reduction of the renal depth errors in up to 25%, especially in patients with variability in renal depth.

I. Introduction

SEVERAL authors have shown that the inter-patient variability in skin-to-kidney center distance have a significant influence on measurement of absolute renal function using planar static scintilographic images [1,2].

When orthogonal posterior planar images are acquired for absolute renal function evaluation, attenuation correction is performed by multiplying the total counts for each kidney region of interest (ROI) by the attenuation correction factor $e^{\mu d}$, where d is the distance between the kidney centroid and the posterior skin outline, and μ is the attenuation coefficient [3]. This method is significantly affected by the kidney depth estimation, which is usually determined by calculations based on patient's weight and height [4, 5], and by the attenuation coefficient of this body region [3]. The most traditional method for renal depth (RD) estimation was developed by Raynaud, and is used in clinical practice [5]. However, this method does not provide true depth values for inter-patient variability, kidney misplacement or renal transplants [1]. Lateral measurements from the kidney-to-skin distances have been used to provide accurate measures and can be more practical for routine clinical studies. However, this distance is usually measured by hand [2].

The aim of this work was to implement and validate a plugin named RDM (*Renal Depth Measurement*) for the software ImageJ [6] to measure the renal depth on lateral planar renal scintigraphy, with a flexible design for academic research and clinical environment in Nuclear Medicine. Monte Carlo simulated images, generated by SimSET code [7], were used for RDM plugin validation, using five anthropomorphic GSF family voxel phantoms [8].

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II. Materials and Methods

A. Monte Carlo Simulation

Planar lateral scintilographic images were modeled using low-energy high-resolution (LEHR) parallel collimator, 10% gaussian energy resolution and 20% photopeak energy window centered at 140 keV (^{99m}Tc). The projection image was binned in a 128 × 128 pixels matrix of pixel size of 0.3125 cm, and field of view (FOV) of 40 × 40 cm^2. Different relative uptakes from normal (50% - 50%) to abnormal distributions in the left kidney (10% - 90%; 20% - 80%; 30% - 70%; 40% - 60%) and right kidney (90% - 10%; 80% - 20%; 70% - 30%; 60% - 40%) were simulated for five anthropomorphic phantoms (Baby, Child, Helga, Donna and Golem), developed by Petoussi-Henss and collaborators (2002), called GSF family voxel phantoms, which have different anatomical characteristics, gender and age (**Error! Reference source not found.**).

The true RD values on Table I were measured directly over the phantoms, based on kidney's center of mass, using the ImageJ plugin named *Sync Measure 3D* [10].

TABLE I
GSF family voxel phantoms characteristics

Phantoms	Age (years)	Weight (kg)	Renal Depth (cm)	Kidney Volume (cm^3)	Height (cm)	Gender
Baby	0.15	4.20	R*- 2.44 L*- 2.38	R*- 14.77 L*- 14.07	57	F*
Child	7.00	21.70	R*- 4.23 L*- 4.57	R*- 74.62 L*- 104.31	115	F*
Helga	26.00	81.00	R*- 8.00 L*- 8.77	R*- 200.47 L*- 170.60	170	F*
Donna	40.00	79.00	R*- 8.30 L*- 8.60	R*- 143.02 L*- 124.42	170	F*
Golem	38.00	68.90	R*- 6.78 L*- 6.51	R*- 151.56 L*- 149.17	176	M*

* R represents the right kidney; L represents the left kidney, F and M correspond to Female and Male.

The application of Raynaud's renal depth formula with these phantoms produced the following results: Baby RD = 2.55 cm, Child RD = 3.84 cm, Helga RD = 6.59 cm, Donna RD = 6.69 cm and Golem RD = 6.23 cm.

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For obese adults, Raynaud has introduced a modification in his original formula, considering an additional thickness factor [5]. With these considerations, Donna and Helga phantoms, classified as obese, had their RD modified, resulting in the values: Donna RD = 8.85 cm and Helga RD = 8.65 cm.

B. RDM Plugin for ImageJ

The RDM code was written in JAVA and implemented as a plugin for ImageJ software. A graphical user interface for the input parameters was developed (Fig. 1).

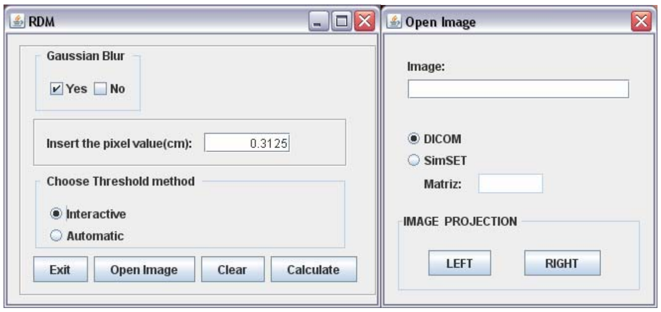

Fig. 1. Graphical user interfaces of RDM plugin.

The RDM estimation is based on thresholding combined with morphological filtering (erosion and dilation), which is done separately for kidney and body delimitation. The RDM plugin input parameters are: image pixel size (cm); application or not of a gaussian blurring filter; selection of thresholding method (interactive or automatic); and opening DICOM or SimSET simulated images. The selection of LEFT or RIGHT button is necessary for right or left RD measurement.

After opening the lateral scintilographic renal images, the procedure for RD determination follows the steps:

1. If the gaussian blurring filter is selected, the kernel parameters can be set by user (radius) and displayed (Fig. 2). This blurring filter is used to remove the high frequency noise inherent to nuclear medicine images that have low counting, and it is crucial for the body posterior skin line thresholding.

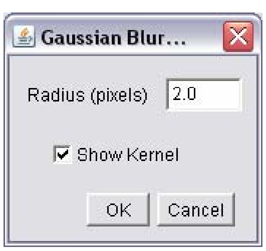

Fig. 2. Graphical user interfaces of gaussian filter.

2. The thresholding method can be chosen between two options: interactive method (scroll bar, with histogram visualization) (Fig. 3), and automatic method (Sahoo's thresholding method [9]). CALCULATE button starts the RD calculation. Selection of the region of interest in the binary image and the kidney centroid determination are automatic. Kidney centroid-to-limit of FOV distance is calculated using the pixel size.

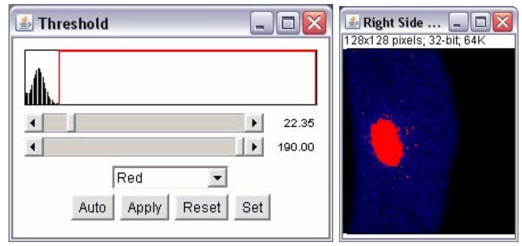

Fig. 3. Graphical user interfaces of interactive method.

3. The same procedure is applied for the body thresholding. The body skin-to-limit of FOV distance is calculated in the same height of kidney centroid, in the same line of projection.

4. Finally, kidney centroid-to-limit of FOV image distance is subtracted of body posterior skin-to-limit of FOV image distance, and RD measurement is calculated.

C. Data Analysis

RD was measured in simulated lateral imaged (Fig. 4) for all phantoms, using the RDM plugin. The results were compared with the true RD values and those calculated with Raynaud formula.

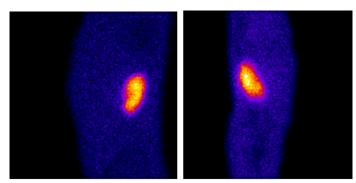

Fig. 4. Example of lateral simulated images of Golem and Child phantoms.

The lateral images with different relative uptakes were analyzed individually using the interactive thresholding method (with and without gaussian filter) and the automatic one (with gaussian filter).

The results from RDM plugin and Raynaud's method were compared with the true RD values (Table I). The error of RD value was calculated by the Equation (1):

$$Error = \frac{true.renal.depth - measure.renal.depth}{true.renal.depth} \times 100\% \qquad (1)$$

III. RESULTS

The results showed that there is a reduction of the RD error in up to 25% using the RDM plugin for measuring kidney depth, relating with Raynaud's formula calculated using the weight and height of the patient.

For interactive thresholding defined by user, the application of the gaussian blurring with kernel radius 2 showed RD results with true values correlation between R = 0.990 and R = 0.994 for all relative uptakes.

The manual choice of threshold value is poorly reproducible and dependent to the user experience to determinate the kidney and body contour delimitation.

Figure 5 shows the scatter plot of RD using RDM plugin for all relative uptakes in the right kidney, compared with the true values. The errors of the depth measurements using RDM plugin compared with the true values are between -18% and 10%. The Raynaud's RD values are around the true values for small depths and remarkably wrong for higher renal depths, related with Donna and Helga phantoms. These values can be corrected using the obese considerations, but it does not deal with the difference between each kidney depth.

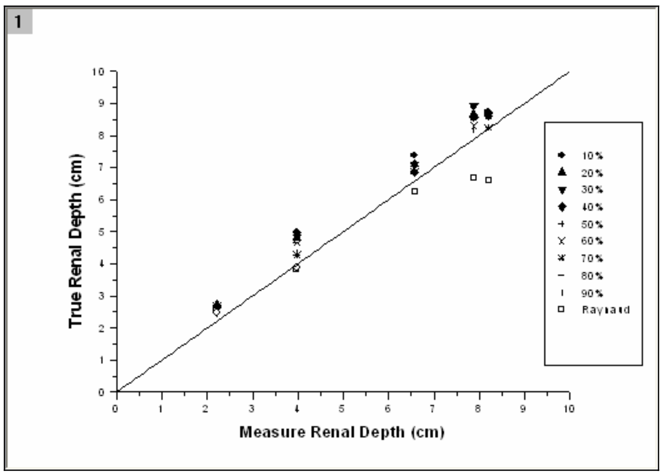

Fig. 5. True values of right renal depth and those determined using RDM plugin (interactive thresholding method). Open squares are RD calculated by Raynaud's formula (without thickness considerations for obese cases).

RDM plugin with automatic thresholding can measure the interpatient variability of renal depth, contrariwise to the Raynaud's formula. The measurements using RDM plugin with automatic thresholding showed the best results and true values correlation between R = 0.994 for right kidney and R = 0.997 for left kidney, for all relative uptakes. The errors using RDM plugin compared with true RD are around -7% and 10%.

The automatic method is reproducible and user independent, being indicated for nuclear medicine clinical practice for renal function evaluation.

Figure 6 shows the scatter plot of RDM plugin for all relative uptakes in the left kidney, compared with true RD. The open squares were obtained using Raynaud's formula, with obese considerations only for Donna and Helga phantoms.

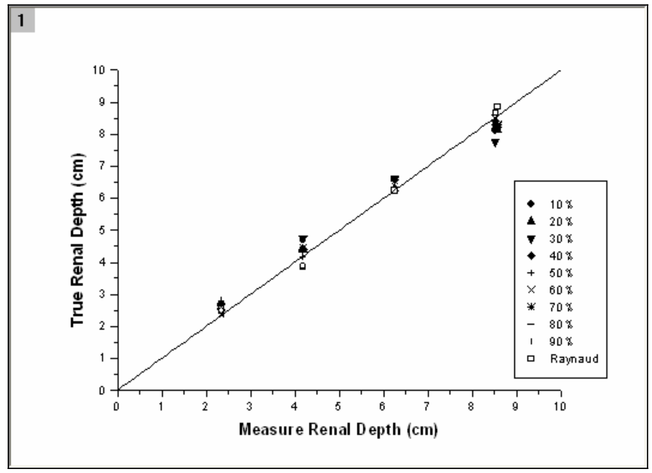

Fig. 6. True values of left renal depth and those determined using RDM plugin (automatic thresholding method). Open squares are the RD calculated by Raynaud's formula with obese considerations.

IV. Discussion

The user choice of thresholding value for the body was identified as the most critical parameter for reproducibility in the RDM plugin using the interactive thresholding method. This method is highly user dependent and is not indicated for clinical practice. The higher errors have occurred in those images with low relative uptakes, where is quite difficult to identify the threshold value. The difficulty occurs remarkably when the low uptake kidney is superimposed by the high uptake kidney.

RDM plugin with automatic thresholding methodology has showed reliability and robustness for different relative kidney uptakes. The results showed differences in the RD values when RDM plugin is used, in comparison with the Raynaud formulae, especially when differences between kidneys depths are detected, as in Donna and Helga phantoms. For that reason, RDM plugin is suggested mainly for those patients with assymetrical kidneys. The RD formulae suggested by Raynaud is applicable only for symmetrical kidneys.

V. Conclusion

A critical review of RD calculation using Raynaud formulae was realized using the RDM plugin developed for ImageJ. The plugin validation using scintilographic simulated showed that the Raynaud's RD estimation is not accurate when the patients don't have depth symmetry between kidneys. Other authors proposed different formulae, as Lythgoe [4]. But this method is valid only for paediatric and symmmetric cases as Raynaud's method. The availability of a free tool for automatic renal depth calculation, as RDM plugin for ImageJ, can improve the use of lateral scintilographic images for renal function evaluation, allowing individual RD measurements for attenuation correction in nuclear medicine practice.

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