Measurement of Renal Dimensions to Determine Standard Reference Renal Volume Model for Clinical Application in Ghana

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ABSTRACT

The study is based on measurements of renal dimensions to determine standard reference renal volume model and renal volumetric ellipsoid coefficient. Two methods, Voxel count method and rotational renal ellipsoid equation were the two measuring tools used with an integrated MVL application software platform. The procedure involve measurement of linear dimensions together with using the snake technique to draw the region of interest (ROI) for the volumetric measurements. These were done to obtain: renal length, lateral diameter, A-P diameter and the total number of voxels to estimates the renal volume. These parameters were used to calculate renal volume using the rotational renal ellipsoid equation as well as using the Minitab statistical software to model renal volume equation. The reference standard renal volume was also determined using water displacement with the Archimedes' principle. The average renal shape index and its dispersion (i.e. covariance matrix) was approximately 1±0.02. The male average measured values for right and left kidneys were as follows: renal length, 103.35cm and 105.13cm, lateral diameter, 60.79 and 60.40 and A-P diameter, 44.12 and 44.95 and renal volume; 146.74cm³ and 151.76cm³ respectively. Furthermore, the female average measured values for right and left kidneys were as follows: renal length, 101.43 and 102.98, lateral diameter, 59.20 and 59.02 and A-P diameter, 43.09 and 44.82, renal volume 142.04cm³ and 148.29cm³ respectively. The average estimated renal volumetric ellipsoid coefficient (VeC) was 0.53. However, various variations for both male and female, with their corresponding right and left kidneys were, 0.5283, 0.5297, 0.5280 and 0.5304 respectively. The reference renal dimensions including the standard renal volume and renal volumetric ellipsoid coefficient are recommended for clinical application in Ghana.

Keywords : Renal volumetric ellipsoid coefficient, renal shape index, renal volume, rotational ellipsoid equation, MVL DICOM

I. INTRODUCTION

Medical imaging is described as the method for noninvasive assessment of physiological and anatomical information about human tissues or organ, by analysing patterns observed within the imaged tissues or organ [1]. In addition, the analysis and interpretation of these pattern for diagnostic and or therapeutic decisions are based on observable pattern of various parameters which a trained clinician looks for: these manifest as morphological and functional changes. Some useful parameters of the acquired image in radiological examinations include volumetric and linear measurements. These parameters enable differentiation between normal and abnormal tissues by the differential radiation dose distribution based on their morphological and contrast variations [1]. These patterns are used to determine whether tissues are benign or malign, and intact or repaired. Medical imaging can thus be used to test the effectiveness of remedies and evaluate the effects of treatments for specific diseases and are display in the form of organ model [2].

These organ models have gradually gained prominence in medical image analysis and clinical research. [1, 2]. Furthermore, these models are used to establish standard reference values that aid radiologists, nuclear medicine
experts and oncologists to make important diagnostic and therapeutic decisions by comparing patient’s organ parameters to these reference values [2]. In addition, modeled standard reference values like renal volume provides more accurate assessment of the renal size than the traditional method of using renal length to estimate renal size without available baseline reference values [2]. The establishment of basic radiological reference linear renal dimensions, like, renal shape index, Anterior-Posterior (A-P), longitudinal and lateral diameters are important for the diagnosis and prognostic evaluation of nephropathies. In addition, these linear dimensions are also use to design area and volume models. Indeed, the reference information from the designed models can be used as standard to test future research data as well as to explain anatomic variations between individuals of the same population and across populations [3].

In applied physics, well-developed human organ system models are described by mathematical expressions [1]. These expressions are converted to computer aided designed (CAD) models for physical visualized analysis, in terms of visual indicators and graphic user interface (GUI) for clinical application [1]. Currently, image assisted construction of organ models are design using 6D (x, y, z, time, colour and user define) volume element (voxel) model of various reconstructed images, based on their varied grey level values. The differentiation of the grey value areas in these organs are done by the process of image segmentation [4, 5]. In the case of CT scan, gray values represented by the Hounsfield numbers are replaced by the organ identification numbers in a container called voxel. This voxels are describe by a single data point, representing a regularly spaced in three-dimensional grid. This may present a single piece of data, such as an opacity or a multiple pieces of data such as opacity and color. Depending on the type of data and the intended use of the dataset, several voxels can be reconstructed or approximated through interpolation to form an entire volume [6]. In view of this voxel are used in medical image analysis to represent the smallest 3D unit of various organs volume, which are estimated from the pixel size in addition to the slice thickness.

There are two ways by which voxel representation of the structures of human organs models can be done; these are; the statistical shape model and the statistical appearance model [7]. The statistical shape model represents the shape information, such as renal dimensions (A-P diameter, renal length and lateral diameter), renal volume and renal surface area [1, 7]. These are regarded as the most useful tools for studying variations in anatomical shape of organs and has been widely used in medical image analysis, such as, medical image segmentation, shape registration and interpretation [1].

A. Objectives

The aims of the study is to

- Measure renal dimensions in order to determine standard reference renal dimensions and volume models for clinical application.
- Determine renal volumetric ellipsoid coefficient and renal shape index to predict individual renal volume using ellipsoid equation for clinical application.
- Reviewed and compare the established renal dimension and renal volume estimates with international recommendations and reference values and make appropriate recommendations.

B. Literature Review

A number of publications appeared in literature in an attempt to describe renal dimensions and other related parameters by various institutions and organizations. Most of these studies are based on measurements of longitudinal diameter, anterior-posterior (A-P) diameter, transverse diameter, renal surface area and renal volume. These parameters provided standardized range of estimates of normal renal sizes by these organizations and individuals [8-28]. However, African clinicians and researchers are yet to be part of these significant developments.

Various studies estimated renal volume using a known pixel size and a slice thickness for computation. A number of studies to measure renal dimensions in order to predict kidney size concluded that longitudinal diameter varied between 10.2 cm to 11.8 cm±2.3cm on the left and 9.8 cm to 10.9 cm ±2.1cm on the right. Transverse diameter varies between 58.0 cm to 6.25 ±0.67 cm on the right and from 6.01 to 6.43±1.7cm on the
right and A-P diameter varies between 4.06 cm to 4.73 cm ± 0.65 cm on the right. 4.15 to 4.88 ± 0.95 cm on the left kidney. It has also been reported that renal volumes varies between 132-196 ± 35.05 cm³ for the left kidney and 128.4 cm³ to 194±28.17 cm³ for the right kidney for male. The studies also shows that the female kidney volume varies between 134cm³ to 186.5±23.56 cm³ for right kidneys with corresponding left kidney volume estimated to varies between 136cm³ to 193.1±34.77 cm³ [15]. Another radiological organ measurements shows that normal adult renal weight varies between 173.0 to 196.3 ± 41.0 g [15]. Most of the study concluded by predicting that kidney sizes diminishes with advancing age, due to parenchymal reduction of the kidney [16].

II. METHODS AND MATERIAL

A. Materials

The material used include: The Vernier caliper (Figure 1) was used to measure the dimensions of the kidney and the Triple-beam balance (Figure 2) to measure the weight. The beaker for the application of the Archimedes principle of volume measurement. Five different types of MDCT Machine (Figure 3), with slices variation of between 16 slice to 640 slice. The images (Figure 4 ) that met the selection criteria were copied onto DVD and transfer onto the the MVL application workstation (Figure 4). The MVL user interface enable it to be implemented in any advance computer system.

B. Methodology

The activities before measurements include:
Identified and code images that met the selection criteria for transfer on to the MVL application platform.

Reconstruct images at 5 mm to unify the measuring process in all the CT centers.

The images were then copied from the image archiving and storage system called the PACS from all the 10 CT centers onto DVD and transferred onto MVL application platform and ready for measurements.

C. Measurements of Linear Renal Dimensions

The first to be measured were the three linear dimensions, described as longitudinal diameter or the renal length, transverse diameter or the lateral diameter (renal width) and the A-P diameter (renal thickness). All kidney dimensions were measured at maximum values of strictly longitudinal, Anterior-Posterior and transverse sections through the center of the kidney. The renal length were measured using the coronary images while the axial images were used to measure A-P and lateral diameters. The width and thickness were measured in the transverse plane perpendicular to each other and the longitudinal axis of the kidney. The level of this transverse section was placed at the level of the hilum.

Two different methods were used to measure longitudinal diameter (LNG) on the coronary images: The first method of measurements was done by drawing a single straight line from one edge of the renal parenchyma to another end with the application software tool on the MeVisLab (MVL) platform as shown in Figure 5. This was repeated three times and average of the three measured values calculated as the renal length. Secondly, the renal length was calculated from axial slices by multiplying the slice thickness by the number of slices between the superior and inferior tips of the kidneys. This were also repeated three times and the average value estimated.

In addition, two other linear parameters were measured: the lateral diameter (LT), measured from the lateral extent of the kidney to the renal sinus and anterior-posterior (A-P) diameter measured perpendiclar to the lateral diameter as shown in Figure 3.6. The two measurements were repeated three times and the average values of both parameters estimated to represent the average lateral and A-P diameters.
The second component of the study was the measurements of renal volume from contiguous CT slices with voxel measuring tool on the MVL application software as shown in Figure 8. These measurements were done using 3D volume-rendered image of the kidney shown in Figure 3.4. The maximum length of the kidney was measured in the longitudinal plane and was visually estimated to represent the largest longitudinal section. Two different methods were used to calculate renal volumes.

The first method was the calculation of the total renal volume by using the voxel-count method on the MVL application software. With a region of interest (ROI) drawn on each of the two kidneys on each slice to indicate the renal boundaries. The total voxel was automatically generated on each slice by taking the sum of the voxel lying within the boundaries, including the central sinus fat but excluding perinephric fat as much as possible.

With a known pixel size, slice thickness and the total number of voxels (as shown in Figure 9 with black arrow). The renal volumes were computed for each patient using the equation below.

That is, \( RV = \text{Total number of voxels} \times \text{slice thickness} \times \text{pixel length} \times \text{pixel width} \).

The advantage of using this method is that the shape of the kidney is irrelevant during measurements. An average of three voxel-count measurements and three other repeated measurements was used as the reference-standard renal volume.

Indeed, this method of volume measurement may result in partial voluming, which occurs when voxels contain both kidney and surrounding tissue, could lead to an overestimation of the renal volume when all such voxels

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**Figure 7** Renal Surface Area

**Figure 8.** Measurements of RSA and RSI

**Figure 9.** Automated calculated of total number of voxel count.

**D. Measurements of Renal Volume**
are included within the boundaries of the kidney. To avoid this overestimation, the segmentation line was drawn at the halfway point of the change in signal intensity, between the kidney and the surrounding tissue and use as reference measuring point in all the slices.

A second method to estimate renal volume was by the Archimedes principle. Here renal volume was estimated using the fluid displacement principle refers to, as Archimedes principle, which states that; the volume of displaced fluid is equivalent to the volume of an object fully immersed in a fluid or to that fraction of the volume below the surface for an object partially submerged in a fluid. The volume and mass of the kidneys were measured from Cadavers during autopsy on fresh dead bodies. The process involve clamping the kidneys before anastomosis and slowly lowered the kidney into a large glass beaker placed on a Triple-beam balance and the displayed volume estimated. Here a large glass beaker was placed on the Triple-beam balance (Figure 10) and calibrated by aligning the reading to the zero mark and the spring elongation ensure to read zero as well. The beaker was then fill with water to about 3/4 capacity and placed on the pan of the triple-beam balance. The triple-beam balance was then recalibrated or realigned to the initial line by moving the moveable masses.

Next, the kidney was lowered and completely submerged in the water and the volume determined, by finding the difference between the initial volume of the water reading and the displaced volume reading. An average of three readings were taken and mean value estimated. At the same time, the difference between the total combine weight of the beaker and the water from the total combined weight of the beaker, water and the kidney represent the renal weight. The average of three repeated measured values was determined as the renal weight.

E. Measurements of Renal Parameters

Four important parameters associated with the linear renal dimensions and volume measurements were also estimated. These include: Renal shape index (RSI), renal surface area (RSA), relative renal length (RRL) and relative renal volume (RRV). First, the renal shape index was estimated by using the ratio of the renal length to the sum of lateral and A-P diameters. Mathematically, RSI is estimated as:

$$RSI = \frac{\text{renal length}}{\text{renal width} + \text{renal thickness}}$$  \hspace{1cm} (1)

That is with known A-P diameter, renal length and the lateral diameter, equation 1 was used to estimate the renal shape index. Secondly, renal surface area was estimated by using the MVL application software tool to map out the kidney contour on a slice that contain the total surface area of the kidney as shown with white arrow on Figure 7. This was done by manually tracing the boundaries of the surface area of the kidney on the slice that contain the complete renal surface. The total number of pixels were automatically generated (Figure 3.9) by MVL software based on the region of interest (ROI) lying within the surface boundaries of the kidney. The measurements were repeated three time and the average value estimated. With the known pixel size and the total voxels, RSA was estimated. This was done using the relation

$$RSA = \text{pixel size x number of total pixels}$$  \hspace{1cm} (1)

Furthermore, two relative renal parameters were also estimated and describe as relative renal length and relative renal volume. The relative renal length (RRL) was determined by dividing either the right renal length (RR_{L}) or the left renal length (LR_{L}) by the total renal length (sum of the left renal length and right renal length). In addition, the relative renal volume (RRV)
was also estimated by dividing either the right renal volume (RRV) or the left renal volume (LRV) by the total renal volume (sum of right renal volume and left renal volume).

\[
RR_{L} = \frac{RRV}{RR_{L} + LRV} \tag{3}
\]

\[
RR_{V} = \frac{RRV}{RR_{V} + LRV} \tag{4}
\]

The renal volumetric ellipsoid coefficient, was estimated by dividing the measured renal volume by the product of renal length, renal width and renal thickness. It represents the constant of proportionality in the ellipsoid equation. The K-values were determined by using the ellipsoid equation for estimating renal volume defined as:

\[
RV = K * \text{renal length} (RL) * \text{renal thickness} (RT) * \text{renal width} (RW). \text{Implied},
\]

\[
K = \frac{RV}{RL * RT * RW} \tag{5}
\]

Therefore, with a known renal volume by the voxel count method, renal length, renal width and renal thickness by linear measurements by MVL. Then $K^*$ was estimated and the standard reference ellipsoid equation with known $K^*$ defined as:

\[
RV = K^* * RL * RT * RW \tag{6}
\]

III. RESULTS AND DISCUSSION

The basic relationship between the various parameters in tables and graphical representation are discussed here. Presentation of the summarized data and the analysis are shown below. All the measured primary data parameters are in the unit of mm, unless otherwise stated.

A. RESULTS

GRAPHICAL REPRESENTATION

Figure 11. Age and gender variation of Renal Length

Figure 12. Age and gender variation of Renal Volume
**Figure 13.** Male age variation of Renal Length

**Figure 14.** Female age variation of Renal Length

**Figure 15.** Male age variation of Renal Volume

**Figure 16.** Female age variation of Renal Volume

**Figure 17.** Age variation of Renal Volume

**Figure 18.** Age variation of Renal Length

**Figure 19.** Age variation of Renal Length and Renal Volume
B. Regression Analysis

Determination of RV Using $R_e$ (Male Linear Renal Dimension)

Model Equation

$$RV = 0.53 R_e + 1.19 \quad (7)$$

\[RV = 0.52 R_e + 1.81 \quad (8)\]

Figure 20. Renal volume in relation to $R_e$ variations for age and gender

Determination of RV Using $R_e$ (Female Linear Renal Dimension)

Model Equation

$$RV = 0.52 R_e + 1.81 \quad (8)$$

Figure 21. Renal volume in relation to $R_e$ variations for age and gender

D. Model Ellipsoid Equation

**MALE ELLIPSOID EQUATION**

20-40 $RV = 0.5287 \times RL \times RT \times RW$

41-60 $RV = 0.5300 \times RL \times RT \times RW$

61-80 $RV = 0.5295 \times RL \times RT \times RW$

**FEMALE ELLIPSOID EQUATION**

20-40 $RV = 0.5288 \times RL \times RT \times RW$

41-60 $RV = 0.5290 \times RL \times RT \times RW$

61-80 $RV = 0.5295 \times RL \times RT \times RW$

**MEAN FEMALE RENAL ELLIPSOID EQUATION:**

$$RV = 0.5292 \times RL \times RT \times RW$$

**MALE RENAL ELLIPSOID EQUATION:**

$RV = 0.5290 \times RL \times RT \times RW$

**FEMALE RENAL ELLIPSOID EQUATION:**

$RV = 0.5292 \times RL \times RT \times RW$

**GENERAL RENAL ELLIPSOID EQUATION**

$RV = 0.53 \times RL \times RT \times RW$

**E4.1M**

**E4.1F**

**E4.3A**

D. Discussions

**Demographic Statistics**

This section deals with the exploratory and inferential statistical analysis of the data obtained from the total sample population. The analysis focuses on the detailed description of the obtained data with respect to certain demographic factors. These include age and gender variation of renal and body parameters in relation to exposure and dose parameters based on the various standard acquisition protocols. The measured parameters were based on the population distribution of the sample population of Ghana, as presented by Ghana statistical service department [20]. Summary of the sample demography are shown in Table 4.1.
Table 1. Sex And Age Distribution of Data.

| Age group | Gender | Sample size | No of Kidneys | Percentage (%) |
|-----------|--------|-------------|---------------|----------------|
| 20-40     | Male   | 108         | 216           | 61.71          |
|           | Female | 67          | 134           | 38.29          |
|           | TOTAL  | 175         | 350           | 100            |
| 41-60     | Male   | 119         | 238           | 46.12          |
|           | Female | 139         | 276           | 53.88          |
|           | TOTAL  | 258         | 516           | 100            |
| 61-80     | Male   | 89          | 178           | 39.21          |
|           | Female | 138         | 276           | 60.79          |
|           | TOTAL  | 227         | 454           | 100            |
| 20-80     | Male   | 316         | 632           | 47.88          |
|           | Female | 344         | 688           | 52.12          |
|           | TOTAL  | 660         | 1320          | 100            |

Renal Parameters

Base on the selection criterion only images with two kidneys were measured and analyzed and presented as left and right kidneys to the spine. In all, six renal parameters (3 measured and 3 estimated) were analyzed. The male renal dimensions on the right of the spine are tabulated in Table 2.

Three other important renal parameters were estimated, these include: renal volume (RV), renal shape index (RSI) and renal volumetric ellipsoid coefficient (VeC). Highlight of the summarized statistics are shown in Table 3.

Renal volume is an important determinant factor during renal development, the hypothesis of various renal dimensions were tested with ages (20 to 80 years) and gender (male and female) variations. The period between 20 to 80 years is considered significant as it followed renal developmental pattern.

The study shows that male renal size starts early decline before age 60 years than female but at a slow rate while female renal size decline after age 60 years but with a faster rate as shown in detail primary raw data Table 2 in appendix. In addition, the overall age and gender renal size reduces significantly after age 80 years as shown by the graphical relationship in Figure 11 and 12. There is however very little variation between age group 20-40.
and 41-60 years, but significant between age group 41-60 and 61-80 years. Furthermore, both genders in the visual indicators and graphical representation shows similar variation. Generally, the study shows that the male renal parameters is larger than the female renal parameters. The general renal size reductions were extremely significantly with left and females kidneys. The reductions for renal volume were 1.89% between the age range of 20-40 to 41-60 years and 15.64% between the age ranges of 41-60 to 61-80 years for the right kidney. Similar observations were seen in the left kidney. However, the reductions were pronounce in the female kidneys as shown in the summarized Table 4.2 and Table 4.3. There is very little difference between the left and the right renal size (renal volume, renal length, renal width and renal thickness) as shown in figure 3 to 8. As a result relative renal length and volume shows approximately 50% in both right and right with length and right kidney. This is a great renal development factor that are used for clinical decision. The male mean estimated values were 0.4959 and 0.5041 for right renal length and renal volume respectively. While the female average relative left renal length and renal volume were 0.4919 and 0.5081 respectively.

IV. CONCLUSION

All the measured renal dimensions were within the theoretical range of accepted values, out of the three parameter, the longitudinal diameter was found to be the largest, this was followed by transverse diameter and then the A-P diameter was consider to be the smallest. Indeed, there was a positive correlation between these parameters. The study unveil the fact that renal size (length, width and thickness) diminishes with aging, this is due to parenchymal reduction in the elderly.

The findings of this study suggest that the anatomical description based on 3D CT models could provide evaluation of the anatomic characteristics of the kidneys of potential live kidney donors. The renal volume data in the form of 3D volumetric analysis of CT data as shown could be a promising alternative to nuclear renography in potential kidneys donors in terms of anatomical description. The findings also conclude that the results could be used to study renal development in Ghana.

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