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Determination of the Relationship between Renal Volume Model and Related Body Indices for Clinical Application in Ghana

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ABSTRACT

The study was done to establish the relationship between measured renal volume and body parameters to estimate standard reference value of renal volume related body parameters (RV-BMI, RV-BSI and RV-BSA) in Ghana for clinical application. The estimates were done based on age and gender variation and compare the established standard reference renal volume with its related body parameters. The weight and BMI measuring machine together with tape measure and glass beaker were the measuring tools used. The procedure involve measurement of body height and weight and using the estimated values to calculate BMI with the BMI calculator. It also involve using DuBois formula to estimate local standard reference values of BSI and BSA in Ghana. The reference standard renal volume was determined using water displacement with the Archimedes' principle to confirm the established values in Ghana. These value were compare with established standard reference renal volume model in Ghana which were estimated using abdominal images on MeVisLab application software platform and determined the relationship between these parameters. The determined Ghanaian standard reference renal volume were: 146.74cm3, 151.76cm3, 142.04cm3 and 148.29cm3 for male and female, with its corresponding right and left kidneys respectively. The estimated mean BMI, BSI and BSA were; 25.19kg/m2 39.81 kg/m2 and 2.02m2 for male and 21.91kg/m2 36.58kg/m2 and 1.69m2 for female respectively. Hence from these set of values, the relationship between renal volume and its related BMI was determined to be 6.04cm3-kg/m2 for male and 6.47cm3-kg/m2 for female. While the male RV related-BSA was also determine to be 74.05cm3-m2 and 84.09cm3-m2 for female. Finally, the renal volume related-BSI was also estimated to be 3.81cm3-kg/m2 for male and 3.88cm3-kg/m2 for female. The standard reference renal volume related BMI, BSI and BSA are recommended to be used for renal assessment for clinical application in Ghana.

Keywords : Body Surface Area, Body Mass Index, Body Surface Index, Body Shape Index, Renal Volume

I. INTRODUCTION

1. Objectives

The aims of the study are to:

- ✓ Determine the relationship between reference renal volume model with that of BMI, BSI and BSA as predicted by mathematical expressions for clinical application.
- ✓ To test the hypothesis that, renal volume, body mass index, body surface index and body surface area grow proportionally at various age groups for clinical application.
- ✓ Reviewed and compare the established body parameters and renal volume estimates with international recommendations and reference values and make appropriate recommendations.

In medical environment estimated body indices are a regular physical checkup parameters in daily clinical practice. This enable a basic health status of a patient to be estimated for further examination to be carried out for diagnostic decision. The most common checkup parameter include: body weight, height, Body mass index (BMI), body surface area (BSA), body shape index (aBSI) and body surface index (BSI). All these parameters are related to estimated body weight and body height. The BSI/aBSI and BSA parameters are less affected by abnormal adipose mass [4, 5, 6]. As a result there are consider to be predictors of internal structure or organs morphology including renal mass/volume [5, 10]. Therefore the measured parameters (BMI, BSI and BSA) give an estimates of internal organs morphology or other dimensional analysis [8, 9, 10]. This method is used as the first clue for morphological condition of the internal organ. This is due to its considerable accuracy and adaptability in organ volume and its simplicity than real measurements. Therefore deviation from normal reference value may call for further detail analysis.

Furthermore, these body parameters are important indices that relate renal volume, which is regarded as the most precise indicator of renal size [9]. It is of interest to note that renal size assessment are not widely used clinically due to the inconvenience and the tedious nature of its assessment. In addition, it is also partly because of the complex renal shape. Therefore renal size assessment are done based on related body indices. As a result in clinical environment factors such as BMI BSA and BSI are used indirectly to estimate renal size [11]. Therefore standard reference BMI, BSA and BSI values may serve as a preliminary method of accessing renal size.

Indeed, estimated renal volume in relationship with other body parameters is key to the understanding of morphological and functional information about kidney size. Renal volume is considered to correlate well with body mass index, from a number of publications [12]. Other publication suggests that BMI is the second most useful and simplest method of estimating renal volume as an adjunct to treatment decision making after BSA [6], which is closely related to BSI. However, in cases where BSA and BSI values are less accurate at extremes of height and weight, BMI may be a better estimator.

2. Basic Principles

The relationship between BMI and Renal volume (RV) is determine mathematically by dividing the renal volume by it corresponding BMI and described as:

$$RVBMI = \frac{RV}{BMI} \qquad 1$$

$$\mathrm{RV} = \mathrm{K\,BMI} \qquad 2$$

The relationship between BMI and renal volume are analyzed using major axis regression analysis with Minitab statistical application tools as applied to any two or more unknown relationship.

This unique parameter is also related to other body and organ volume measurements and described as BSA and BSI-related body parameters without direct measurement. The relationship between renal volume, BSA and BSI is described as the renal volume BSA or BSI and define as the ratio of renal volume divided by the total body surface area or body surface index [79, 80]. Mathematically RV-related BSA or RV-related BSI are expressed as;

$$\mathrm{RVBSA} = \frac{\mathrm{RV(mL)}}{\mathrm{BSA}\ (m^2)} \qquad 3$$

$$\mathrm{RVBSI} = \frac{\mathrm{RV(mL)}}{\mathrm{BSI}(kg/m^2)} \qquad 4$$

Hence, the relationship between RV and BSA were modeled as:

$$\mathrm{RV} = \mathrm{RVBSA}\left(\frac{m^3}{m^2}\right) \mathrm{x\ BSA}\ (m^2)$$

$$\mathrm{RV}\ (m^3) = \beta \mathrm{\ x\ BSI}\ (m^2) \qquad 5$$

Where β is equal to RV-BSA

While the relationship between BSI and renal volume were established as

$$\mathrm{RV} = \mathrm{RVBSI}\left(\frac{m^3}{kg/m^2}\right) \mathrm{x\ BSI}\ (kg/m^2)$$

$$\mathrm{RV}\ (m^3) = \mu \mathrm{\ x\ BSI}\ (kg/m^2) \qquad 6$$

Where μ is equal to RV-BSI

II. METHODS AND MATERIAL

3. Materials

Figure 1. BMI Calculator

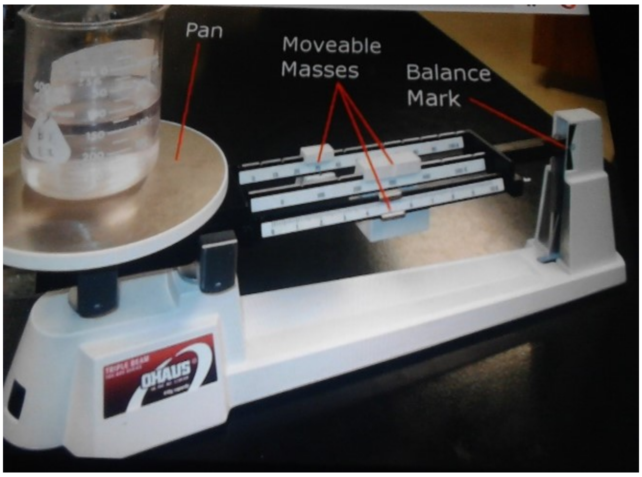

Figure 2. Measurements Of Kidney Volume

Figure 3. Measurements of Renal Volume

Figure 4. Total number of voxel by MVL

4. Methodology

Two different methods were used to estimate the BMI: By either direct registration with the BMI automatic measuring system (*figure 1*) or by calculation from separated measurement of height and weight as defined by *equation 3.1*. Whilst BSA was estimated indirectly using Du Bois formula shown as in *equation 3.2* or the general relation as in *equation 2*. In addition, BSI was estimated by dividing measured body weight by BSA, shown in *equation 3.4*. Renal volume was also estimated by using the ellipsoid equation, through measurements of renal length, renal width and renal thickness and with a known renal volumetric ellipsoid coefficient, the renal volume was estimated.

Furthermore, the relationship between renal volume and BMI, BSA and BSI was established by using Minitab statistical software. The major regression analysis produce a modeled relationship between the body parameters and the renal volume.

In addition, the related renal volume-BMI, BSI and BSI experimental hypothesis were estimated by dividing the renal volume by its BMI, BSA and BSI to get the renal volume related BMI, BSA and BSI (RV-BMI, RV-BSA and RV-BSI) respectively, for both left and right kidneys.

In clinical application standard reference renal volume is estimated by the application of ellipsoid equation or the Archimedes principle of volume estimates. The ellipsoid method involve the product of renal length, renal width and renal thickness, together with the standard reference renal volumetric ellipsoid coefficient. While the Archimedes principle of volume estimate involve measuring the change in volume in a measuring cylinder of a displaced fluid, which is an equivalent to the volume of an object fully immersed in a fluid

Mathematical the three parameters were estimated as:

The BMI is determine by using the relation:

$$BMI = \frac{Weight}{Height^2} \qquad 3.1$$

The BSA is estimated by using the relation:

The most widely used BSA calculated formulae is the *DuBois* and DuBois *formula expressed as:*

$$BSA = w^{0.425} * h^{0.725} * \ 0.007184 \qquad 3.2$$

where w and h are the weight and height respectively

or

4.1 Measurement of BMI, BSI And BSA-Related Renal Volume

$$BSA = \frac{\sqrt{Weight+Height}}{60} \qquad 3.3$$

While the aBSI and BSI is generally estimated as:

$$BSI = \frac{Weight}{BSA} \qquad 3.4$$

Mathematically, the ellipsoid equation is express as:

$$\mathrm{RV} \ = \ K^* * (a) * (b) * (c) \qquad 3.5$$

where K* is the renal volumetric ellipsoid coefficient and a, b, c are the renal length, renal width and renal thickness respectively. However, in Ghana this relationship is define as:

$$\mathrm{RV} \ = \ \mathrm{a} \ \times \mathrm{b} \ \times \ \mathrm{c} \ \times \ (0.53) \qquad 3.6$$

While the Archimedes principle of volume estimate is express as:

$$\mathrm{RV} \ = \ \mathrm{FV} - \mathrm{IV} \qquad 3.7$$

where FV is the final volume of liquid in cylinder together with kidney and the IV is the volume of liquid without kidney in cylinder.

4.2 Modeling Process

The model equations describes the relationship between the renal volume and the body indexes (BSA, BSI and BMI). This enable the prediction of renal volume when either BSA, BSI or BMI or both are known. This involve the use of statistical analysis with the Minitab statistical tool.

Mathematically the renal volume was divided by the body parameter to estimate the renal volume related BMI, BSA and BSI. These were describe as RV-BMI, RV-BSA and RV-BSI.

Therefore, equation 3.9, 3.12 and 3.13 are modeled relationship between renal volume and BSI, BSA and BMI. These parameters are important for use during body organ development, especially for a progressive period of childhood to adulthood and to the aged, where most renal failures occurs.

III. RESULTS AND DISCUSSION

4.3 Graphical Representation And Modeled Equations

Determination of RV using BSI

RV = 0.20BSI + 133.51 4.1F

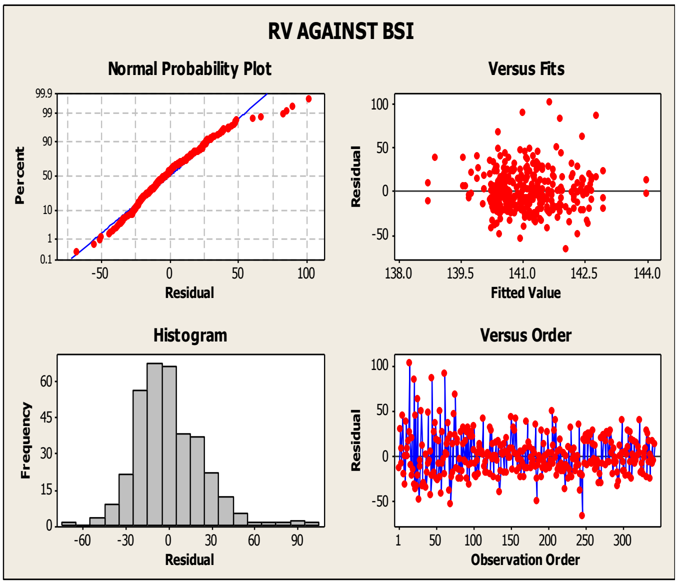

Figure 5. Renal volume in relation to BSI variations for age and gender

Determination of RV using BMI

RV = 0.95 BMI + 120.58 4.2F

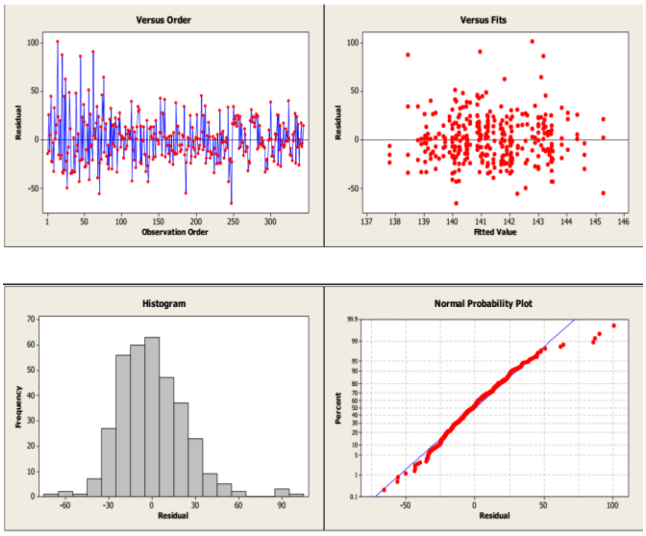

Figure 6. Renal volume in relation to BMI variations for age and gender

Determination of RV using BSA

RV =1.19 BSA + 139.33 4.3F

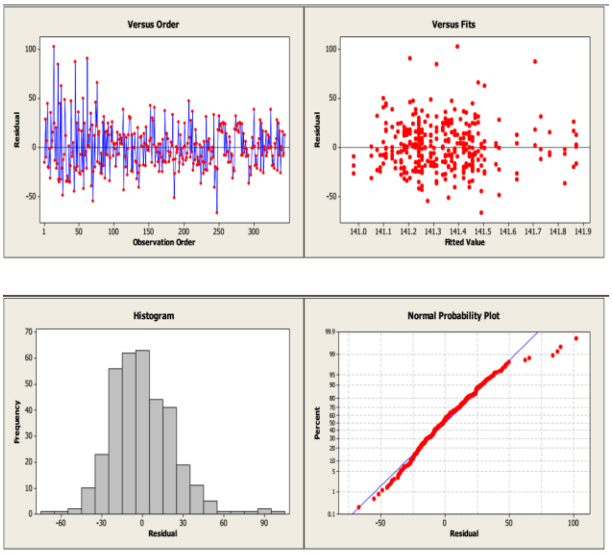

Figure 7. Renal volume in relation to BSA variations for age and gender

Determination of RV using BSI

RV = 156.74 - 0.19BSI 4.1M

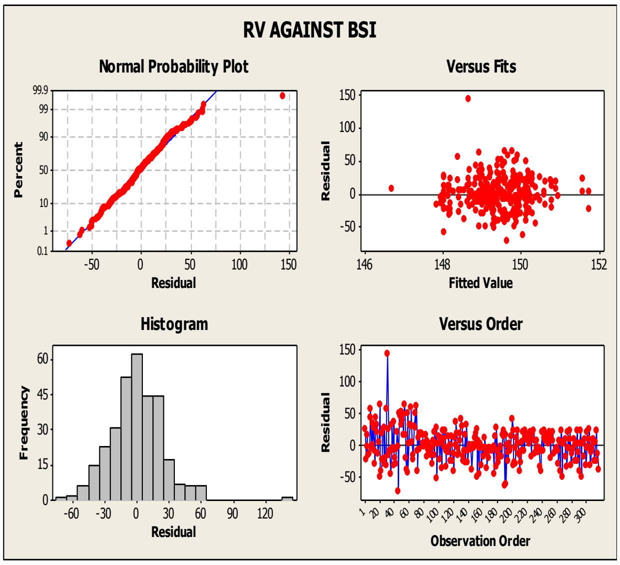

Figure 8. Renal volume in relation to BSI variations for age and gender

Determination of RV using BMI

RV = 0.53 BMI + 135.97 4.2M

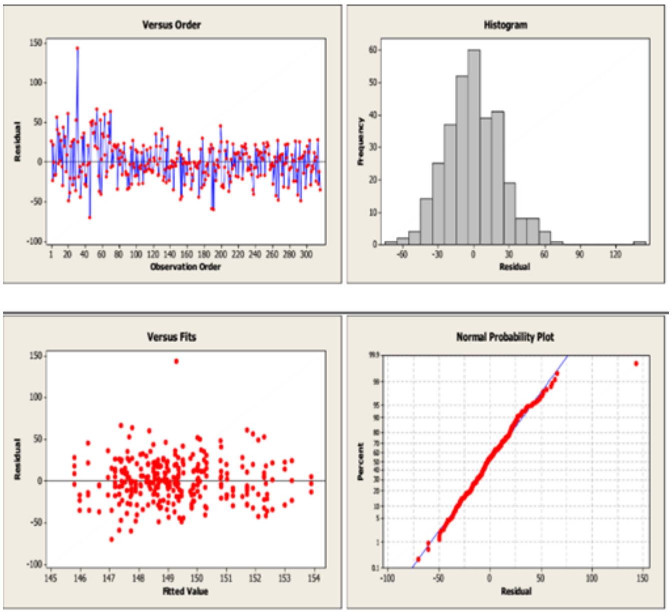

Figure 9. Renal volume in relation to BMI variations for age and gender

Determination of RV using BSA

$$RV = 15.58\ BSA + 117.59 \qquad 4.3M$$

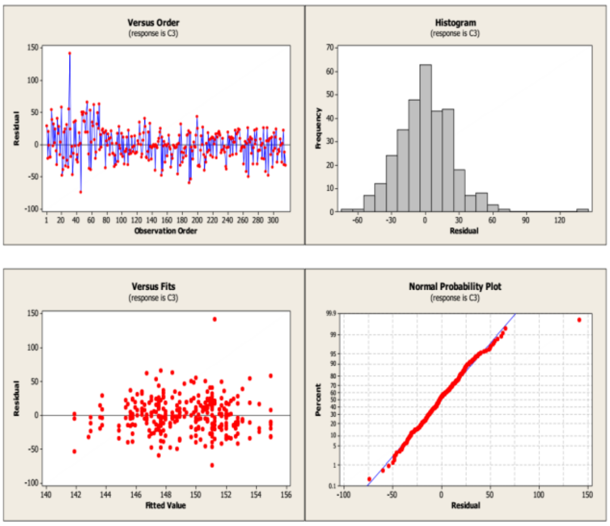

Figure 10. Renal volume in relation to BSA variations for age and gender

4.4 Statistical Representation

Table 4.1. Age dependent parameters

MALE	AGE	**RVBMI$_R$**	**RVBMI$_L$**	**RVBSA$_R$**	**RVBSA$_L$**	**RVBSI$_R$**	**RVBSI$_L$**
20-40	years	$cm^3/kg/m^2$	$cm^3/kg/m^2$	cm^3/m^2	cm^3/m^2	cm^3/m^2	cm^3/m^2
MEAN	33	6.552362	6.86488	86.3062	90.471	4.02543	4.21123
MAX	40	8.474599	8.89245	111.04	120.817	5.41454	5.56679
MIN	20	4.118182	4.75664	57.7033	56.3457	2.58739	3.1382
MAX/MIN	2	2.05784956	1.86948	1.92432	2.1442	2.09267	1.77388
41-60							
MEAN	52	6.687177	7.06236	86.8221	91.6758	4.00336	4.22437
MAX	60	10.96346	11.7077	150.192	158.226	6.63378	8.27344
MIN	41	4.547578	3.98284	57.3645	55.6446	2.44953	2.53063
MAX/MIN	1.46	2.41083495	2.93954	2.61821	2.8435	2.70818	3.26932
61-80							
MEAN	68	5.762394	6.12266	74.531	79.1756	3.42241	3.63744
MAX	80	8.84522	13.6289	121.269	189.241	5.51184	8.35985
MIN	62	3.585404	2.952	40.0866	38.007	2.18278	1.79721
MAX/MIN	1.29	2.4670079	4.61682	3.02518	4.97912	2.52514	4.65156
20-80							
MEAN	45	5.945618	6.12347	72.9716	75.1229	3.75087	3.86736
MAX	80	12.36111	10.8137	144.442	126.361	7.55434	6.60868
MIN	20	2.980456	2.67772	35.5278	36.2108	1.87593	1.80511
MAX/MIN	4	4.14738886	4.03841	4.0656	3.48959	4.027	3.6611
FEMALE							
20-40							
MEAN	31	6.36709	6.50492	77.4891	79.0192	4.04336	4.13814
MAX	40	12.36111	10.8137	144.442	126.361	7.55434	6.60868
MIN	20	3.727819	3.65546	47.9315	47.79	2.42405	2.41512
MAX/MIN	2	3.31590938	2.95824	3.01351	2.64408	3.11642	2.73638
41-60							
MEAN	51	6.227306	6.40649	76.648	78.8925	3.911	4.02803
MAX	59	10.81077	9.19569	124.985	119.709	6.21127	5.84974
MIN	42	4.005936	4.0594	51.7694	56.067	2.70048	2.78341
MAX/MIN	1.41	2.69868765	2.26528	2.41426	2.13511	2.30006	2.10164

4.5 Discussions and Analysis

4.5.1 Relationship between Renal Volume and Body Indexes

The hypothesis that, BSA, BSI, BMI and renal volume (RV) grow proportionally at various age groups were tested. These were done by dividing the renal volume by its BMI BSA and BSI to get the renal volume related-BMI, BSA and BSI (RV-BMI, RV-BSA and RV-BSI). No significant variation (less than 5%) between left and right kidneys and a normal distribution for all kidneys regardless of the patient's age were found. The mean male renal volume related-BMI BSA and BSI were 5.95, 72.97, 3.75 for right and 6.12, 75.12 and 3.87 for left kidneys respectively. In addition the mean female BMI, BSA and BSI-related renal volume were 6.29, 81.77, 3.77 for right and 6.64, 86.40 and 3.99 for left kidneys respectively.

The RV-BMI, RV-BSA and RV-BSI has a common normal range for all age groups with various variations shown in Table 4.2. As the variation of these parameters from the standard reference value within a specific age group may require further investigations. In addition, RV-BMI, RV-BSA and RV-BSI alleviates the correct evaluation of a patient's renal volume regardless of age and depend largely on gender. It however reveals a pathological gender influences by the observation and that a kidney that deviates from a standard reference BMI, BSA and BSI-related-renal volume parameters may call for further investigation. The renal volume related-BMI, BSA and BSI were determined and found to positively correlate for both male and female as shown by the model equations.

Table 4.2. Renal Volume and Related Parameters

STATISTICS	AGE	RV_R-BMI	RV_L-BMI	RV_R-BSA	RV_L-BSA	RV_RBSI	RV_L-BSI
MALE	year	$cm^3/kg/m^2$	$cm^3/kg/m^2$	cm^3/m^2	cm^3/m^2	$cm^3/kg/m^2$	$cm^3/kg/m^2$
MEAN	45	5.945618	6.12347	72.97161	75.12287	3.750874	3.867361
MAX	80	12.36111	10.81373	144.4419	126.3605	7.554344	6.608683
MIN	20	2.980456	2.677722	35.52779	36.21075	1.875925	1.805108
MAX/MIN	4	2.27	1.93	2.58	2.19	2.27	1.93
FEMALE							
MEAN	46	6.286997	6.643007	81.77413	86.39891	3.774333	3.985528
MAX	80	10.96346	13.62885	150.1923	189.2413	6.633782	8.359845
MIN	20	3.585404	2.952	40.08656	38.007	2.182782	1.797214
MAX/MIN	4	2.93	3.11	2.72	2.88	2.41	2.55

To test the hypothesis that, body surface area, body mass index and renal volume grow proportionally at various age groups. There were insignificant differences between the various age groups and a normal distribution for all kidneys with the BMI-related renal volume regardless of the patient's age. The details are shown in Table 4.1 while the summarized analysis are shown in Table 4.2. Furthermore, there were slight variation between left and right kidneys and its corresponding gender variation. Therefore the study reveal that BMI, BSA and BSI-related renal volume is an important parameter for accessing pathological condition for clinical application. As deviations of these parameters from normal this determined standard reference BMI, BSA and BSI-renal volume may indicate pathologic conditions. Finding from this study reveal that BMI, BSA and BSI-renal volume measurements correlated better than any single measured parameter such as weight and height. This will help to unveil very early damaging influences of the renal performance due to renal diseases and or aging factors. As a results assessing renal size in relation to body indices based on reference data of renal volume measurements should be made based on individually assessment. Furthermore, changes in body parameters in relation to renal volume from one examination to the next may be an important indicator for the presence or progression of disease. In addition, relative renal volume in term of BMI, BSA and BSI, between left and right kidneys greater than 55% of the total renal volume or less than 45%, or roughly a difference between both renal volumes greater than 20%, should prompt the suspicion of a one-sided infection as predicted Th. Scholbach et al [11]. Finally, each individual can be followed up smoothly according to his individual age variation, which, as with renal volume, BMI and BSA describes the individual prognosis of the kidney volume size as defined by the reference values. As a results growth deformity, which are often encountered early in chronic renal disease, can be unmasked easily. All this promises a true advantage for detection of renal disease by precocious detection of creeping renal volume changes.

IV. CONCLUSION

This study agreed with Th. Scholbach et al that renal volume correlated significant and positive with BSI, BSA and BMI [11]. The modeled equations in section 4.2, show the relationship between estimated body parameters and renal volume during clinical assessment of patients' images. The estimated renal volume correlated well with age, this is important because age is known as one of the risk factors of renal graft survival. Hence will play an important role during renal grafting. It is also of interest to note that, body indexes related renal volume is insignificantly with age. This accession has been confirmed by the study with various different age groups as shown in Table 4.1.

V. RECOMMENDATION

RVBMI, RVBSA and RVBSI calculations are recommended and the observation of the relative renal volumes for all abdominal CT examinations in adults and this could be extrapolated in children and adolescents as well the elderly for kidney development and assessment.

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