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Development of Filtration Model of Human Kidney Using Multivariable Regression

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ABSTRACT: *Lack of adequate facilities required to assess kidney functions and high cost of treatments to diagnose patients with kidney related diseases in Nigeria prompted this work. The purpose of the study is development of filtration model in human kidney using multivariable regression analysis. Human renal function data of fifty healthy individuals comprising male and female were obtained from Ahmadu Bello University Teaching Hospital Shika, Nigeria. Multivariable regression analysis tool was utilized in Microsoft excel spreadsheet on the data collected. Probability value (P-value), was used to test the significance of the regression on the data analyzed. Correlation coefficient (r) was used to examine the relationship between the estimated glomerular filtration with the predictors. The analysis conducted on both male and female data were found to be statistically significant (P-value<0.05). Positive correlation coefficient (r=0.91) was confirmed between estimated glomerular filtration rate and weight in male. Similar result was also obtained in female (r=0.84). An inverse relationship was observed between estimated glomerular filtration rate and age in both male and female with correlation coefficients (r) of -0.23 and -0.53 respectively. The predictive glomerular filtration rate models could be used by Nephrologist in Nigeria for the assessment of glomerular filtration rate in both male and female kidney.*

Keywords: *Diagnose, Glomerular filtration rate, Human renal function data, Multivariable Regression, Nephrologist.*

I. INTRODUCTION

In the late 1960s and early 1970s many researchers began to develop mathematical models of the kidney. This research has progressed from the mid-1970s to this day with many variations, additions, and improvements [1],[2]. Mathematical modelling is the formulations or an equation that expresses the essential feature of physical systems or processes in mathematical terms. Modelling and simulation are used in today's scientific and technological world because of the ease with which they can be used to analyze real systems. Lack of adequate facilities required to assess kidney functions and high cost of treatments to patients with kidney related diseases have remained a challenge to the nephrologists and the less privileged in Nigeria. The purpose of the study is development of filtration model in human kidney using multivariable regression analysis. The developed models will serve as a rapid diagnostic tool that is expected to compete with the modern medical equipment that is used for the assessment of Glomerular filtration rate in human kidney.

II. MATERIALS AND METHODS

2.1 Materials

(i) Human renal function data
(ii) Windows 7 PC

2.2 Methods

2.2.1 Collection of Human Renal function Data

Human renal function data of fifty (50) healthy individuals, comprising thirty (30) male and twenty (20) female, who spanned an age range of twenty (20) to seventy (70) years, were obtained from Chemical Pathology Department, Ahmadu Bello University Teaching Hospital, Shika, Zaria, Kaduna State Nigeria.

2.2.2 Glomerular filtration model

Multivariable regression analysis tool was utilized in Microsoft excel spreadsheet on the data collected for both male and female. The coefficients obtained were used to develop predictive models for the estimation of GFR in human with weight, age and blood pressure as the predictors. Probability value (P-value), was used to test the significance of the regression on the data analyzed. Correlation coefficient (r) was used to examine the relationship between the estimated glomerular filtration rate and the predictors. Summary of the output of the analyses were reported in charts and tables.

III. RESULTS AND DISCUSSIONS

3.1 Multivariate regression analyses on human renal function data.

Tables 1 and 2 present the summary outputs of the multivariable regression analysis on male and female data respectively.

Table 1: Summary output of the multivariate regression analysis for Male

	Df	SS	MS	F	P-Value
Regression	3	10153.373	3384.458	7.122	0.001
Residual	26	12354.575	475.176		
Total	29	22507.948			
	Coefficients	Standard Error	T Stat	P-Value	Correlation (r)
Intercept	29.259	37.056	0.790	0.436	
B.P	0.135	0.214	0.630	0.534	0.22
AGE	-0.622	0.368	-1.693	0.102	-0.23
WEIGHT	1.345	0.306	4.401	1.631E-04	0.91

Table 2: Summary Output of the multivariate regression analysis for Female

	Df	SS	MS	F	P-Value
Regression	3	11455.13	3818.3780	11.27226943	0.0003
Residual	16	5419.853	338.74083		
Total	19	16874.99			
	Coefficients	Standard Error	T Stat	P-Value	Correlation (r)
Intercept	48.287	37.056	1.299	0.2122	
B.P	-0.061	0.324	-0.190	0.8521	-0.33
AGE	-1.006	0.353	-2.849	0.0116	-0.58
WEIGHT	1.164	0.251	4.630	2.779E-04	0.84

In Table 1, the P-value was found to be 0.001 (P-value<0.05), this means that, the regression on the data is statistically significant [3]. Furthermore, there are at least 95% chances that there is a true relationship between the output response (GFR) and the predictors. Similarly, Table 2 also revealed that, there is a significant relationship (P-value 0.0003) on female data.

The predictive models for the estimation of GFR in male and female kidney were given by equations 1 and 2 respectively.

$$GFR_{estimated} = 29.259 + 0.135(BP) - 0.622(AGE) + 1.345(WEIGHT) \quad \ldots \quad (1)$$

$$GFR_{estimated} = 48.287 - 0.061(BP) - 1.006(AGE) + 1.164(WEIGHT) \quad \ldots \quad (2)$$

Tables 3 and 4 present the estimated glomerular filtration rate of male and female as a function of Weight, Age and Blood pressure.

Table 3: Estimated glomerular filtration rate for Male

WEIGHT (Kg)	AGE (Years)	BP (mmHg)	GFR (ml/min)
56	20	130	109.6332
52	21	110	100.9374
55	30	120	100.7168
49	32	120	91.40248
78	33	130	131.129
90	35	110	143.3292
60	35	140	107.0227
58	37	160	105.7816
70	42	150	117.4613
100	45	120	151.9005
90	45	120	138.4515
75	45	120	118.2779
89	46	140	139.1777
77	46	130	121.6921
73	47	110	112.9964
67	48	140	108.345

60	50	115	94.31868
55	50	120	88.26758
70	51	140	110.5123
71	51	120	109.1635
70	51	200	118.5933
68	53	130	105.2308
60	53	120	93.12471
78	54	110	115.3636
62	55	120	94.56959
74	55	130	112.0552
85	60	120	122.39
42	60	100	61.86559
62	60	120	91.45728
69	65	110	96.41245

Table 4: Estimated glomerular filtration rate for female

WEIGHT (Kg)	AGE (Years)	BP (mmHg)	GFR (ml/min)
40	25	80	64.77329
60	28	130	81.95535
55	32	110	73.34396
78	34	130	96.86486
52	35	110	66.83668
101	35	110	123.8483
103	38	130	121.9301
61	39	120	72.6716
74	39	110	88.41139
56	40	150	64.00575
85	42	110	98.19315
77	42	120	88.27088
72	43	120	81.44777
75	50	130	77.28489
84	50	120	88.37067
79	52	120	80.54197
85	56	140	82.27213
49	63	130	33.96113
47	70	120	25.20923
65	70	120	46.15229

3.2 Relationship between GFR and weight.

A positive correlation coefficient (r=0.91) was confirmed in male as illustrated in Figure 1, this means that, there is a strong relationship between the estimated GFR and weight [3]. In other words, GFR increase with weight gain due high renal plasma flow which increased systematic arterial pressure [4]. An essentially identical relationship to that observed in male was also present in female as shown in Figure 2 with (r=0.84). Furthermore, the result obtained, replicates that of [5], who showed that measured GFR increased with weight gain.

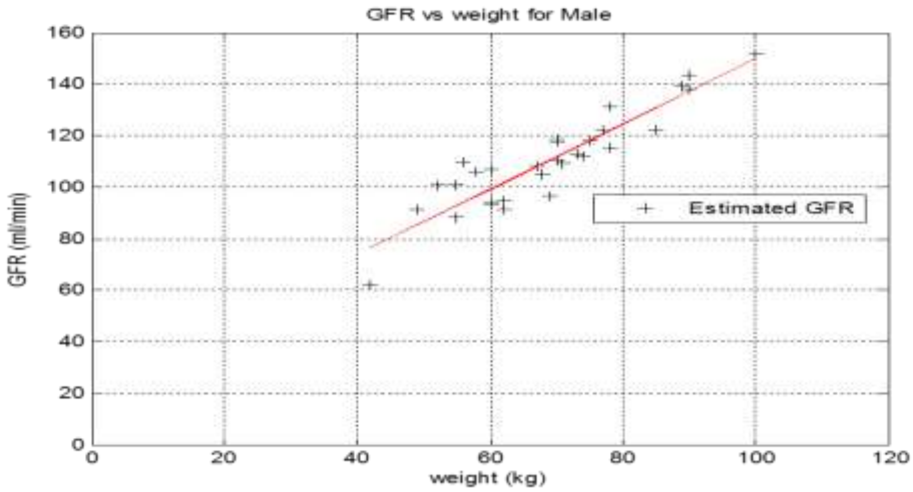

Figure 1: Estimated glomerular filtration rate as a function of weight in male

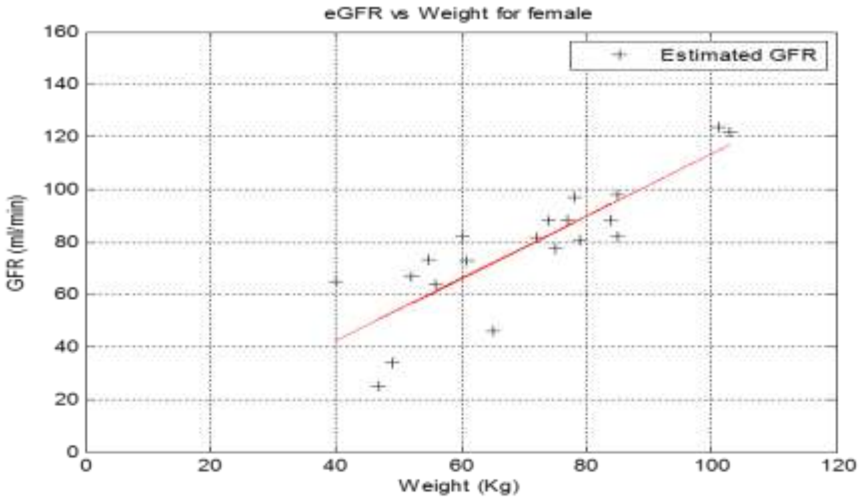

Figure 2: Estimated glomerular filtration rate as a function of weight in female

3.3 Relationship between GFR and Age.

Negative correlation coefficient of (r=-0.23) was observed in male between GFR and age as illustrated in Figure 3. This revealed that the estimated GFR decreased as age increased which also agrees with the findings of [6]. The decline in GFR with aging appears to be a part of normal physiological process of cellular and organ senescence and is associated with structural changes in the kidney [7]. Figure 4 shows similar trend to that observed in male but with a stronger relationship (r=-0.53). These finding provided some evidence that a different adaptive response to renal physiology may exist in male and female [8].

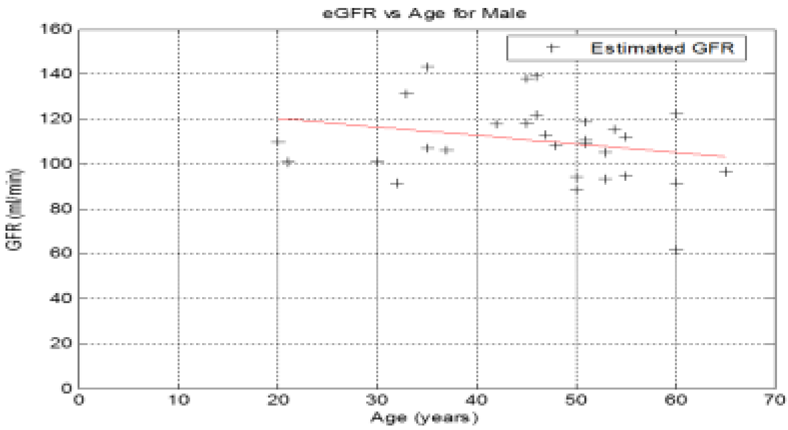

Figure 3: Estimated glomerular filtration rate as a function of Age in male.

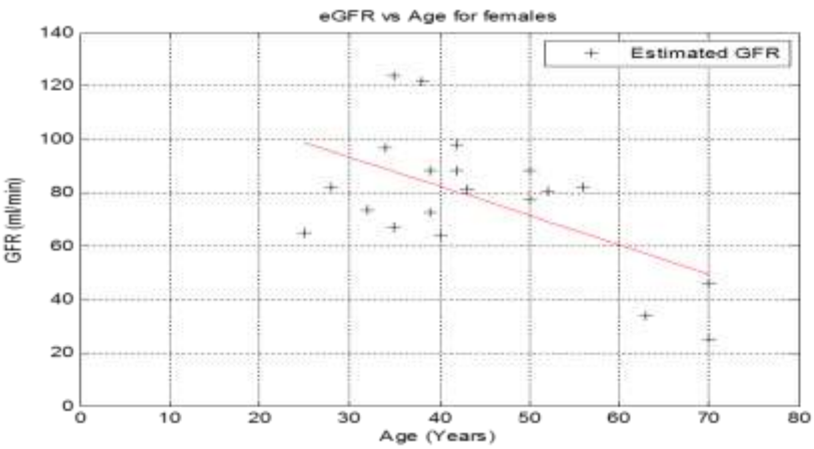

Figure 4: Estimated glomerular filtration rate as a function of Age in female.

3.4 Relationship between (GFR) and Blood pressure.

Shown in Figure 5, a very weak relationship between the estimated glomerular filtration rate and blood pressure was observed (r=0.22). Also, from the Figure 6, a negative correlation coefficient (r=-0.03) was observed. These revealed that there is no significant relationship between the estimated GFR and blood pressure in both male and female [3]. This is due to the fact that, blood pressure has little effect in the determination of glomerular filtration rate in the kidney [4] and [8].

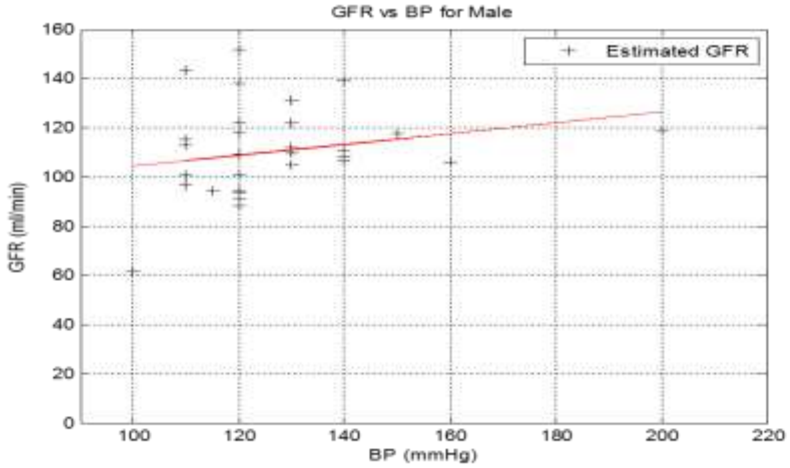

Figure 5: Estimated glomerular filtration rate as a function of BP in male.

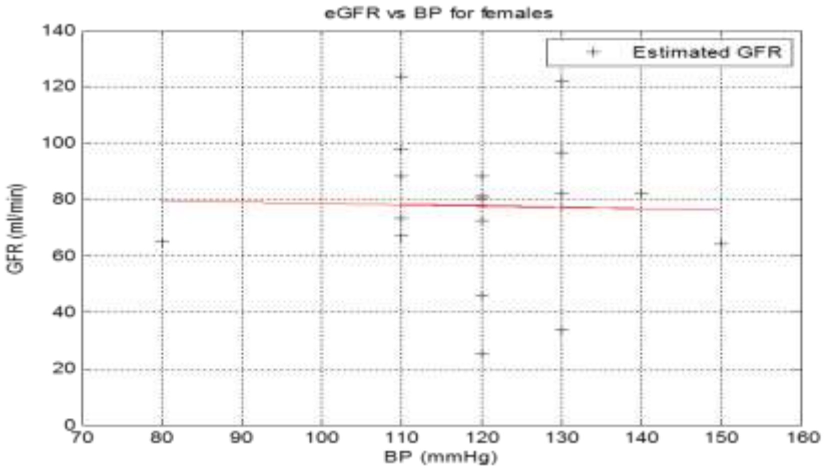

Figure 6: Estimated glomerular filtration rate as a function of BP in female

3.5 Validation of Glomerular Filtration Models

Normal kidney function of healthy individuals has a glomerular filtration rate (GFR) > 80 ml/min [8], [9], [10]. The estimated glomerular filtration rate for both Male and Female obtained in Tables 3 and 4 respectively, were compared with a normal glomerular filtration rate (GFR). In Male, 99% estimated GFR were found to be > 80 ml/min, these clearly shows that the predicted GFR model for male is valid to be use to asses kidney functions of healthy men. However, in Female, only 50% of the estimated GFR were > 80 ml/min, these could be due to the choice of confidence level when carrying out the multivariable regression analysis on female data hence further work should be done.

IV. CONCLUSIONS

Glomerular filtration models for the estimation of glomerular filtration rates in human kidney were predicted and both found to be statistically significant (P-Value<0.05). Hence the model predicted could be used for hypothesis testing to estimate the GFR in adult male and female kidney. However, the GFR models predicted should further be verified with experimental data from different medical establishments. Further work should be done for the prediction of GFR models at 99% confidence level. Research in this area should continue in Nigeria with the aim of creating tools to medical experts for health care purposes.

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NOTATIONS

GFR= Glomerular filtration rate, DF=Degrees of freedom, SS= Sum of squares, MS= mean of square, P= Probability

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