



IJRASET

International Journal For Research in
Applied Science and Engineering Technology



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 12 **Issue:** 1 **Month of publication:** January 2024

DOI: <https://doi.org/10.22214/ijraset.2024.58105>

www.ijraset.com

Call:  08813907089

E-mail ID: ijraset@gmail.com

Mathematical Study on Palatable Diet Administration with a Reference to Diabetes Mellitus on Varying Body Frames - ANOVA Test with PFC Ratio

Mani K S¹, K S Basavarajappa², Ashwini M Rao³, Ashwini.G⁴, Shriya Anil Hardi⁵, Srusti.S⁶, Harsha Teja.k⁷, Sathisha A B⁸

^{1, 2, 3}Department of Mathematics, BIET, Davangere, VTU, Belagavi, Karnataka, India

^{4, 5, 6, 7}Department of Biotechnology, BIET, Davangere, VTU, Belagavi, Karnataka, India

⁸Department of Mathematics, Government First Grade College, Jagalur, Karnataka, India

Abstract: A mathematical model is presented in this paper to compute the palatable prescription of chosen diet for diabetes mellitus type-II using Joselin's principle. Two types of portions of the food as red portion and black portion are chosen for palatable diet with 1:1:1gm equivalent to 4:9:4cal taken as Protein(P), Fat(F) and Carbohydrate(C) respectively. For the analysis, three types of body frames as Small(S), Medium(M) and Large(L) for both men and women aged 19 years and above are considered. A reference to juvenile is introduced for the palatable diet. Differential equations in the coupled form are defined to explain the varying glucose level and varying insulin level. Average calorie values are computed in reference to age and height for the estimation of PFC using linear regression model. ANOVA gives the comparison of results of calorie estimation for palatable diet chosen. With the administration of palatable diet, the values of PFC can be varied to meet the required glucose level of diabetes mellitus type-II.

Keywords: Joselin's principle, Protein, Carbohydrate, Fat, ANOVA, Diabetes mellitus type- II

I. INTRODUCTION

Diabetes is the disorder of metabolism causing excessive thirst and the production of large volume of urine containing excess of sugar. Metabolic disorder is of two types:

I) Diabetes insipidus: This is the rare metabolic disorder in which the body passes large quantity of colourless urine that contains more water causing thirsty, dry hands, constipation. This is due to the failure of kidney's function where in the water is to be reabsorbed.

II) Diabetes mellitus: This is the disorder of carbohydrate metabolism in which sugars in the body are not oxidized to produce energy due to lack of pancreatic hormone insulin. The accumulation of sugar leads to cause of hyperglycaemia in the blood. The disorder may be triggered by the various factors including physical stress, weight loss, retinopathy and hardening of the arteries (atherosclerosis). Also, due to unoxidized glucose, the cells in the lining of blood vessels and other organs may get damaged. The series of such events cause the arteries get clogged and resulting in heart attack and stroke. The systolic and diastolic blood pressure shows the increase from 4.77% to 10.35% when compared to normal values 80-120 mm Hg. As a result the viscosity of blood decreases, the flow rate increases. But due to increase in viscosity, the flow rate decreases in the arteries. Further the micro aneurysms develop in the arteries when the cell function is disturbed. In order to regulate the proper utilization of blood glucose, administration of insulin and palatable diet distribution are necessary for varying body frames to maintain the proper utilization of insulin for the metabolic activities.

A general approach of Gatewood et.al[13] explained the effect of hormone glucose and insulin secreted by pituitary and thyroxin produced by thyroid as simplest mathematical form. Brownlee et. al[9] described glycosylation end products in tissue and the biochemical basis of diabetic complications. They also analysed the fluctuations of chemical compounds in diabetic patients. Kapur[19] presented a compartment model for diabetes mellitus taking the interaction of blood glucose with insulin at different time intervals. Bankroft et.al[5] made a comparative study of dysfunction in men with and without diabetes mellitus. Bartholovistsch et.al[8] studied the behaviour of viscosity of the blood in diabetic cases and non-diabetic cases.

Sathia [28] analysed the treatment of Alpha-Lipoic Acid (ALA) for the improvement of glucose effectiveness in lean and obese patients with type-II diabetes mellitus (non-insulin-dependent diabetes mellitus (NIDDM)). The variations were observed on whole blood viscosity, haematocrit, shear rate and the plasma viscosity. They also explained the fundus appearance in hypersensitive and diabetic, lack of exercise, a poor diet, current smoking and abstinence from alcohol use were all associated with significantly increased risk factors of diabetes. Gary et.al[12] presented the effect of body weight of a free 76 kilojoules (320 calories) daily supplement of almonds for six months. Katiyar and Basavarajappa et.al[20] analysed the diabetes mellitus under palatable composition of quantitative diet with varying body frames. Allick Gideon et.al[1] compared the effects of a caloric high carbohydrate and high fat improves glucoregulation in type- II diabetes mellitus by reducing post absorptive glycogenolysis. Venkatapuram et.al[30] explained metabolic syndrome is considered to be a metabolic precursor of type – II diabetes mellitus and is an independent risk factor in the pathogenesis of atherosclerosis. MeenaVerma et. al[22] presented the effect of increasing duration of diabetes mellitus type –II on glycated haemoglobin and insulin sensitivity. Villegas et.al[31] analysed that high intake of foods with a high glycemic index and load, especially rice, the main carbohydrate contributing food may increase the risk of type- II diabetes mellitus in Chinese women.

Keeping in view of the investigations made by various authors, the present paper concerns the study of mathematical model for diabetes mellitus type-2. The study of palatable composition of quantitative diet using system of coupled linear differential equations is considered in the analysis. Required calorie against the height of human beings is studied as a special case using linear regression model. It is aimed at achieving the required total calorie as the ratio of Ca vs. small, Ca vs. medium and Ca vs. large body frames for men and women with age 25 years and above. Study is focused to improve the outcome of palatable composition in maintaining the blood glucose and insulin levels during fasting (pre-prandial: no caloric intake for the previous 8 hours) and after consuming the breakfast (postprandial: caloric intake in every four hours). Three types of body frames small, medium and large have been considered with an average age variation rate. The initial concentrations of blood glucose and insulin levels are documented at the time of meal-1, meal-2, meal-3 and meal-4 in a successive interval of four hours. The ratio of calorie vs height using regression equation has been computed for various PFC values for three different body frames. Palatable diet under equally divided meals will help the usage of reasonable doses to achieve the closeness of normal blood glucose levels. We have considered three different body frames with different age and height in the regression model for computing the total calorie of PFC using Joslin's principle.

II. FORMULATION

Model refers to the quantities as 'x' for blood glucose level, 'y' for blood insulin level, 'z' for food input, 't' for time and 'I' for insulin input. Under the assumption of the normal fasting level of blood glucose with 70-100 mg/100ml before breakfast and 120-140 mg/100ml following a meal, the gradients of blood sugar (x) and the insulin (y) are modelled as,

$$\frac{dx}{dt} = -\alpha xy + \beta x_0 H(x_0 - x) - \beta x H(x_0 - x) + \gamma Z(t) \quad (1.1)$$

$$\frac{dy}{dt} = (\varphi x) \times H(x - x_0) - (\varphi x_0) H(x - x_0) - \psi y_0 + \xi I(t) \quad (1.2)$$

where α , β and γ are the positive constants called sensitivity values for insulin, the low blood sugar level, high blood sugar level and the input level respectively for the sugar level (gradient). We consider φ , ψ and ξ as the positive constants and are taken as the sensitivity values for high blood sugar level, insulin level and the input level respectively, 'H' is the unit step function which controls the quantity of food intake sensitivity of the diet plan of four different meals.

The input to the blood sugar level is via food source. The food store can be assumed to be filled periodically and the contents at any stage are reduced in a simple exponential manner.

The source term Z(t) in terms of quantity of food can be expressed as,

$$\xi = Z(t) = \begin{cases} 0 & , t < t_0 \\ Qe^{-\delta(t-t_0)} & , t \geq t_0 \end{cases} \quad (1.3)$$

Where Q - quantity of meal, δ - delay parameter and t_0 - time of the meal. Then we take the maximum effect to mean leakage rate as I(t),

The food intake for the first meal is modelled as,

$$I(t) = \frac{\rho t_1}{t_1 - t_0} + bt + k \quad (1.4)$$

Let $t_1 - t_0 = \Delta t = 3$ hours

When $t = 3$ hours, the food intake I(t) is given by,

$$I(t) = \rho + 3b + k \tag{1.5}$$

$$z(t) = Qe^{-\delta(t_1-t_0)} \tag{1.6}$$

Linear regression analysis between the input as variation of height associated with varying body frames give rise to total calorie. Regression coefficients control the change in blood glucose level for the chosen palatable diet for four different meals. The quantities of four different meals in the form of variations of calorie v/s height for various body frames has been taken into consideration in the following regression equation.

$$\mu_{E/T} = \beta_0 + \beta_1 x \tag{1.7}$$

where E-calorie T- height, x- variation of height associated with variation of body frame, $\mu_{E/T}$ -total calorie with PFC, β_0 - regression coefficient for initial set of points(first twomeals)and β_1 – regression coefficient for the normal set of points.

III. ANALYSIS

Equations (1.1) and (1.2) describe the blood sugar and insulin levels. Changing the non-linear term αxy as $\alpha \bar{x}y$ (linear term of x and linear term of y are to be taken as independent Solutions) then,

For $x > x_0, H(x_0-x) = 0$ (by unit step function)

For $t \leq t_0, z(t) = 0, I(t) = 0,$

for which, the equations (1.1) and (1.2) become,

$$\frac{dx}{dt} = -\alpha \bar{x}y \tag{1.8}$$

$$\frac{dy}{dt} = \varphi x - \varphi x_0 - y \tag{1.9}$$

The solution the equations (1.1) and (1.2) give the numerical computation to carry out up to 2nd decimal places since, the third & fourth decimals in each computation is sensibly same.

Equations (1.8) and (1.9) have been analytically solved respectively for x(t) and y(t), using equation (1.7) with $D = d/dx$. Then,

$$x(t) = C_1 e^{m_1 t} + C_2 e^{m_2 t} + x_0 \tag{1.10}$$

$$y(t) = C_3 e^{m_1 t} + C_4 e^{m_2 t} \tag{1.11}$$

The value of x(t) remains within the fasting level x_0 (pre-prandial, before meal - 1). The value of y(t) remains as parallel solution response. Then,

$$x(t) = C_5 e^{m_1 t} + C_6 e^{m_2 t} + x_0 + \frac{\gamma \mu_{E/T} (\psi - \delta) e^{-\delta(t-t_0)}}{\delta^2 - \psi \delta + \alpha \varphi \bar{x}} \tag{1.12}$$

$$y(t) = C_7 e^{m_1 t} + C_8 e^{m_2 t} + \frac{\gamma \mu_{E/T} e^{-\delta(t-t_0)}}{\delta^2 - \psi \delta + \alpha \varphi \bar{x}} \tag{1.13}$$

we redefine the physiological parameters as,

$$x = x^{PD}, y = y^{PD}, C_1 = C_1^{PD}, C_2 = C_2^{PD}, Q = Q^{PD} = \gamma \mu_{E/T}^{PD}$$

For PFC by introducing regression model.

We obtain the net variation of Z(t) as food source, then,

$$\int_{t_0}^{\infty} z(t) dt = \int_{t_0}^{\infty} \mu_{E/T} e^{-\delta(t-t_0)} dt \tag{1.14}$$

For food source z(t) at 4 different meals at the average rate of [1482.76396 – 2550] calories for men aged 25 years and above.

For food source z(t) at 4 different meals at the average rate of [1484.76396 – 1953.66] calories for women aged 25 years and above.

For food source z(t) at 4 different meals at the average rate of [1514.76396 – 2034.77] calories for juvenile aged ½ year and 19 years.

By referring the selection of food with normal time for consumption, let a person eats half meal in 10 minutes (1/6 hours), by equation (1.15), we obtain,

$$\frac{1}{2} \left(\frac{\mu_{E/T}}{\delta} \right) = \mu_{E/T} \int_{t_0}^{t_0 + \frac{1}{6}} e^{-\delta(t-t_0)} dt \tag{1.15}$$

Required calorie limits are computed as [1482.76396 – 2256.277703] for men, [1484.76396 – 2041.277703] for women, [1514.76396 – 2431.277703] for juvenile using Joslin’s Principle [15].

Using C_1^{PD} and C_2^{PD} , x (t) and y (t) in terms of PD are obtained as,

$$x^{PD} = C_1^{PD} e^{-t} \sin t + C_2^{PD} e^{-t} \cos t + \frac{\gamma \mu_{E/T}^{PD} (\psi - \delta) e^{-4.16(t-t_0)}}{\delta^2 - \psi \delta + \alpha \varphi \bar{x}} - \frac{\mu t}{\varphi} + \frac{\psi \mu - \alpha \bar{x} \varphi}{\alpha \bar{x} \varphi^2} \tag{1.16}$$

$$y^{PD} = (C_1^{PD} + C_2^{PD})(0.25)e^{-t} \sin t + (-C_1^{PD} + C_2^{PD})(0.25)e^{-t} \cos t + \frac{\phi \gamma \mu_{E/T}^{PD} e^{-\delta(t-t_0)}}{\delta^2 - \psi \delta + \alpha \phi x} + \frac{\mu}{\alpha x \phi} \tag{1.17}$$

1) Men aged 25 years and above

$$\mu_{E/T_M}^{PD} = \begin{cases} T_{sM}^{Ca} = 964.103896 + (2.6727273)T_{sM}^{PFC} \\ T_{mM}^{Ca} = 244.69 + (4.6036)T_{mM}^{PFC} \\ T_{lM}^{Ca} = -507.86618 + (6.734177)T_{lM}^{PFC} \end{cases}$$

2) Women aged 25 years and above

$$\mu_{E/T_W}^{PD} = \begin{cases} T_{sW}^{Ca} = 66.62749 + (5.11392)T_{sW}^{PFC} \\ T_{mW}^{Ca} = 53.679 + (5.0964)T_{mW}^{PFC} \\ T_{lW}^{Ca} = 16.0714286 + (5.1666667)T_{lW}^{PFC} \end{cases}$$

3) Juvenile (children) aged 1/2 year up to 20 years

$$\mu_{E/T_{ja}}^{PD} = T_{ja}^{PD} = -227.6591085 + [5.854162] T_{ja}^{PFC} \tag{1.18}$$

For general case of liquid diet (LD) and house diet (HD):

$$Q_{LD}^{PD} = T_{LD}^{Ca} = -2650.0 + (29.0)T_{LD}^{PFC} \tag{1.19}$$

$$Q_{HD}^{PD} = T_{HD}^{Ca} = 77.5 + (4.0)T_{HD}^{PFC} \tag{1.20}$$

Where $Q_{LD}^{PD} = \mu_{E/T_{LD}}^{PD}$ and $Q_{HD}^{PD} = \mu_{E/T_{HD}}^{PD}$

Regression equation explains that the variation of height affects the intake of calorie in the palatable diet. As a result the total calorie varies corresponding to the ratio of $\mu_{E/T}$, where $\mu_{E/T}$ denotes the total calorie with, E-calorie T- height.

Values of Q_{LD} and Q_{HD} are compared with new model equations consisting of height of the individual as input and calorie as the corresponding output studied through linear output. Values of $\mu_{E/T_{LD}}$ and $\mu_{E/T_{HD}}$

Values of blood sugar $x(t)$ and insulin $y(t)$ are obtained for four different cases using Joslin's principle [15].

IV. RESULTS AND DISCUSSION

By referring to the palatable composition as Protein: Fat: Carbohydrates (P: F: C), it is observed that, glucose place an important role as metabolic fuel. In general the percentage of carbohydrate ratio is more than protein and fat for the digestion process in relation to the oxidation of P: F: C. Because the input of the carbohydrate will be well utilized by the brain, insufficient quantities to meet the energy demand. The measurements of blood glucose level $x(t)$ and insulin level $y(t)$ from equations (1.16) and (1.17) are functions of time t . The graphs referred to solution of system of differential equations using linear regression model explain the possible (close to the normal calorie range) for the maintenance of normal values of $x(t)$ in response to corresponding values of $y(t)$.

Joslin's Principle used in the present model:

Protein [P] : 1 gm. = 4 calories

Fat [F] : 1 gm. = 9 calories

Carbohydrate [C]: 1 gm. = 4 calories

Men

T_{sm}^{PFC}	T_{sm}^{Ca}	T_{mm}^{PFC}	T_{mm}^{Ca}	T_{lm}^{PFC}	T_{lm}^{Ca}
288	1735	305	1649	328.3	1703.3
313.3	1808.3	331.6	1771.6	360	1916.3
343.3	1881.6	361.6	1909.6	393.3	2141
385	1993.3	403.3	2101.3	430	2388
415	2073.5	440	2270	470	2657.5

Table 1.1 : Total PFC for Men(M), with small(s), medium(m) and large(l) body frames

Women

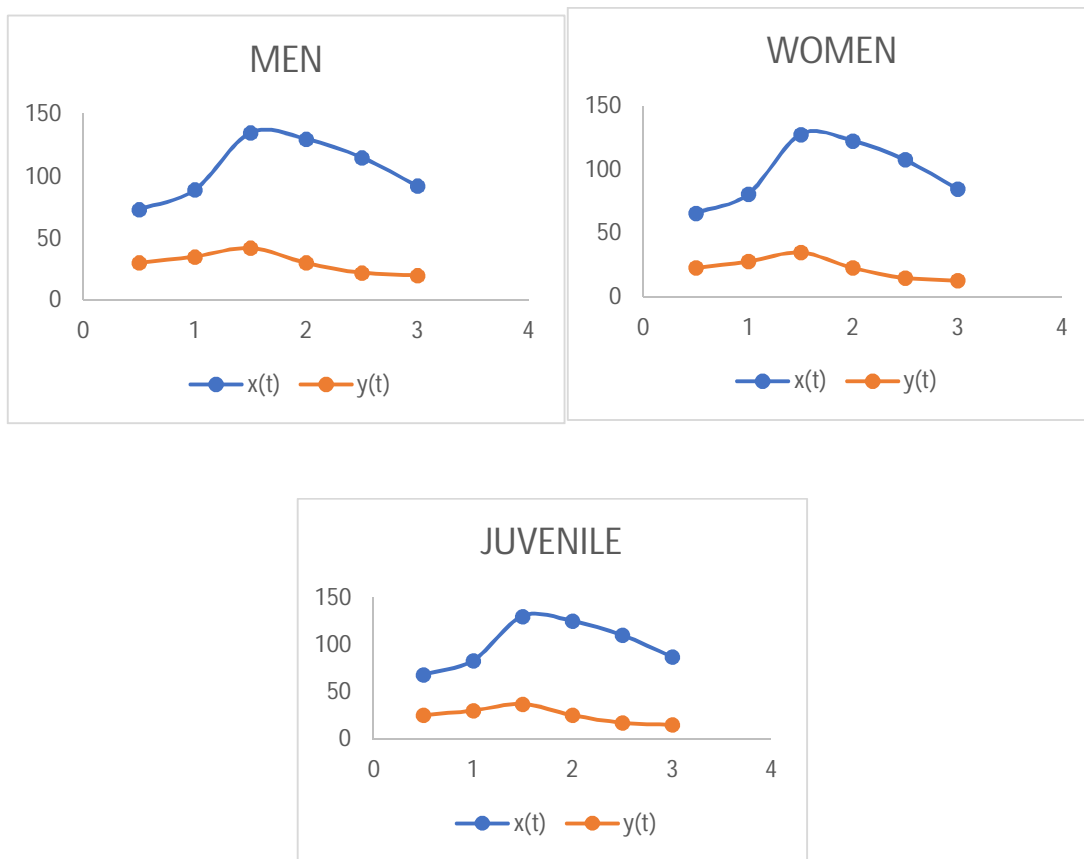
T_{sm}^{Ca}	T_{sm}^{Ca}	T_{mm}^{PFC}	T_{mm}^{Ca}	T_{lm}^{PFC}	T_{lm}^{Ca}
255	1370.67	273.3	1446.67	288.3	1506
275	1473	291.67	1540.3	323.3	1687.67
298.3	1592.3	353.3	1719	348.3	1816
323.3	1720	343.3	1803.67	373.3	1945
345	1831		1939	385	2005

Table 1.2 : Total PFC for Women(W), with small(s), medium(m) and large(l) body frames

Juvenile

PFC _{ja}	J_{ja}^{Ca}
172	779.3
239.67	1175.66
293	1488
352	1831.3
399.5	2111

Table 1.3 : Total PFC for Juvenile with average(a) body frames



REFERENCES

- [1] Allick, Gideon, Bisschop, Peter H, Ackermans [2004], 'A low carbohydrate/High fat diet improves glucoregulation in Type-II diabetic mellitus by reducing post absorptive glycogenolysis', J. Clinical. Endocrinology, Vol. 89, No.12, 6193-6197.
- [2] Athena Makroglou, Jiaxu Li, Yang Kuang [2005], 'Mathematical models and software tools for the glucose-insulin regulatory system and diabetes: an overview' J. Applied numerical mathematics, Vol. 56, 559-573.
- [3] Avudainayagem A, Mishra A, Sundar S, 'Modeling and Simulation'. Narosa Publishing House, New Delhi.
- [4] Bagust A and Beales S [2003], 'Deteriorating beta-cell function in type-II diabetes: a long term model', J. Med, Vol. 96, 281-288.
- [5] Bankroft J and Gutierrez P [1996], 'Erectile dysfunction in men with and without diabetic mellitus: A comparative study', N. Enyl. J. Med, Vol. 13, 84-89.

- [6] Bansal JL, 'Viscous Fluid Dynamics', Oxford and IBH Publishing Company New Delhi.
- [7] Baravkar S G, Jadhav A L, Kitcher S P, 'Computational Mathematics', Mehata Publishing House, Pune.
- [8] Bartholovitsch A, Windberger U, Schwarz G, Czarneci L and Losert U [1999], 'Blood viscosity in diabetic Vs non- diabetic (diabetes mellitus) canine and feline patients', *Biorheology*, Vol. 36, No. 1, 2, 85-86.
- [9] Brownlee M, Cerami A and Vlassara H [1988], 'Advanced Glycosylation end products in tissue and the biochemical basis of diabetic complications', *New England J. Medicine*, Vol. 318, 1315-1321.
- [10] Elizabeth S, Allman, John A Rhodes, 'Mathematical Models in Biology', Cambridge university press, 2004.
- [11] Fredric J Walburn, Deniel J Scheck [1976], 'A constitute equation for whole human blood', *Biorheology*, Vol. 13, 201-210.
- [12] Gary E Fraser, M B, Hannelore W, Bennett, Karen B, Jaceldo and Joan Sabate[2002], 'Effect of body weight of a free 76 kilojoule (320 calories) dailysupplement of almonds for six months', *J. American College of nutrition*, Vol. 21, No. 3, 275-283.
- [13] Gatewood LC E, Askerman J, Rosevear W and Molnar G D [1970], 'Behave, Science' Vol. 15, 72.
- [14] Gefen A, Chen J and Elad D [1999], 'Stresses in the normal and diabetic human penis flowing implantation of an inflatable prosthesis', *J. Med. Biological Engg. Computation*, Vol. 37, 625-631.
- [15] Guyton, *Textbook of Medical Physiology*, IGAKU-SHOIN/ Saunders international edition, 1981.
- [16] Draper N Rand H Smith, [1981] "Applied regression Analysis", New York: John Wiley & Sons.
- [17] Hernandez G, Gayol M C and Rasia M [1999], 'Erythrocyte rheology in diabetes, obesity and hypertension rat genetic model', *Biorheology*, Vol. 36
- [18] Hu, Frank B, Manson, Joann E, Stampfer, Meir J, Colditz, Graham, Liu, Simin, Solomon, Caren G, Willett, Walter C [2001], 'Diet, Lifestyle and the risk of type-II diabetes mellitus in women', *New England J. Medicine*, Vol. 345(11), 790-797.
- [19] Kapur JN [1992], 'Mathematical models in biology and medicine', Revised edition, east west press, New Delhi.
- [20] Katiyar V K, Basavarajappa K S [2003], 'Regulation of blood glucose level in diabetes mellitus using palatable diet composition', *Australian J. Physical and Engineering sciences in medicine*. Vol. 26, 132-139.
- [21] Mazumdar J [1972], 'Biofluid mechanics', World scientific publishing company.
- [22] Meena Verma, Sangeeta Paneri, Preetha Badi, PG Raman [2006], 'Eeffect of increasing duration of diabetes mellitus type-II on glycated hemoglobin and insulin sensitivity', *Indian J. Clinical Biochemistry*, Vol. 21, No. 1, 142-146.
- [23] Murray JD, 'Mathematical Biology', Vol. 17, 3rd edition, Springer.
- [24] Ookawara S, Yano A and Ogawa K [2001], 'Estimate of red cell deformability and plasma viscosity based on flow curve' *J. AIChe*, Vol. 47, 230-238.
- [25] Paolo Magni and Riccardo Bellazzi [2006], 'A stochastic Model to Assess the Variability of Blood Glucose Time Series in Diabetic Patients Self-Monitoring', *IEEE Transction on Biomedical Engg*, Vol. 53, No. 6, 977-985.
- [26] Rajan S K, Anand kumar V and Shefali M Gokhala [2001], 'Study of systemic hypertension as an independent risk factor in the development and progression of diabetic retinopathy', *Indian J. Clinical Practice*, Vol. 12, No.1, 47-50.
- [27] Richard M Behgenstal [2001], 'Management of type-II diabetes mellitus', *Indian J. Clinical Practice*, Vol. 11, No. 11, 37-46.
- [28] Sathia G N [2000], 'Alpha Lipoic acid (ALA) in diabetes', *Indian J. Clinical Practice*, Vol. 10, No. 8, 79-84.
- [29] Vekasi J, Kesmarky G, Cser A, Russai R, Marton Z S, Juricskay I, Hardeman M R and Toth K [2000], 'Hemorheological parameters of patients with retinopathy', *Biorheology*, Vol. 36, No. 1, 2 and 147.
- [30] Venkatapuram, Suneetha, Shannon and Richard P [2006], 'Managing atherosclerosis in patients with Type II diabetes mellitus and metabolic syndrome', *American. J. Therapeutics*, Vol. 13, No. 1, 64-71.
- [31] Villegas, Raquel, Liu, Simin, Yu-Tang [2007], 'Prospective study of dietary carbohydrates, Glycemic index, Glycemic load and incidence of Type-II diabetes mellitus in middle aged Chinese women', *Article in Archives of internal medicine*, Vol. 167, No. 21, 2310-2316.
- [32] Ronald N Forthofer, Eun Sul Lee, Mike Hernandez, "Biostatistics: A guide to design Analysis and Discovery", Second Edition.



10.22214/IJRASET



45.98



IMPACT FACTOR:
7.129



IMPACT FACTOR:
7.429



INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Call : 08813907089  (24*7 Support on Whatsapp)