Original research article

Assessment of Renal Function Using Serum Urea and Creatinine in Type 2 Diabetes Mellitus Patients Receiving Care at Referral Hospitals in Enugu, Nigeria

ABSTRACT

Introduction:
Type 2 Diabetes Mellitus (T2DM) often causes renal dysfunction, which may progress to chronic kidney disease. The aim of the study was to assess the renal function of T2DM patients receiving treatment in referral hospitals in Enugu metropolis by measuring their serum urea and creatinine.

Method:
This comparative cross-sectional study included 160 age and sex matched participants: 80 with type 2 diabetes mellitus (T2DM) and 80 non-diabetic controls. All provided informed consent. Participants were selected using simple random sampling from a defined sampling frame. Sociodemographic data were collected using validated, pretested questionnaires. Laboratory tests involved collecting 3 mL of fasting venous blood from each participant for the analysis of fasting plasma glucose, urea, and creatinine using spectrophotometric methods. Data were analysed using GraphPad Prism version 8.0. Statistical significance was defined as $p < 0.05$.

Result:
Participants with type 2 diabetes mellitus (T2DM) had significantly higher fasting plasma glucose (FPG) concentrations than non-diabetic controls ($p < 0.05$). T2DM participants also had higher creatinine and urea levels ($p < 0.05$). FPG was positively correlated with creatinine ($r = 0.488$, $p < 0.0001$) and with urea ($r = 0.415$, $p < 0.0001$).
.

Conclusion:
This study demonstrates that serum urea and creatinine concentrations are elevated in individuals with Type 2 Diabetes Mellitus and show a positive correlation with fasting plasma glucose levels, suggesting an increased risk of subclinical renal dysfunction. Consistent screening, together with structured patient education regarding glycemic control, is critical to reducing the risk of progression to chronic kidney disease.

Key words:Type 2 diabetes mellitus, renal function, fasting plasma glucose, creatinine, urea,

INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disorder. It is characterized by persistent hyperglycemia due to defects in insulin secretion, insulin action, or both (Banday et al., 2020). Insulin is a pancreatic hormone that plays a central role in glucose homeostasis. Its deficiency or resistance impairs carbohydrate metabolism. Globally, diabetes is a major public health concern. Its rising prevalence contributes greatly to morbidity and mortality (Obianyido et al., 2025).

DM is classified into two primary types. Type 1 diabetes mellitus (T1DM) was previously called insulin-dependent diabetes. Type 2 diabetes mellitus (T2DM) was formerly known as non-insulin-dependent diabetes. Additional forms result from genetic abnormalities or secondary factors, such as medication use, pancreatic disorders, or physiological changes like gestational diabetes in pregnancy. Type 2 diabetes mellitus is the most common form both globally and in Nigeria. It accounts for about 90% of all local cases. T2DM is also one of the major causes of kidney failure(Hoogeveen et al., 2025). Chronic kidney disease (CKD) affects about 50% of patients with T2DM(Siddiqui et al.,2022)

The prevalence of diabetes mellitus (DM) is increasing globally. According to the International Diabetes Federation (IDF), 537 million adults aged 20 to 79 years were diagnosed with diabetes in 2021(IDF, 2021;Hossain et al., 2024). Projections estimate that the number of cases will reach 643 million by 2030 and 783 million by 2045(Liu et al., 2025). In 2021, approximately 24 million individuals in Africa were diagnosed with diabetes. This number is projected to rise by 129 percent, reaching 55 million by 2045(Shaikhomer et al., 2025). In Nigeria, diabetes represents an escalating public health concern. Ezeani et al. (2020) reported a prevalence of 3.3% in southeastern Nigeria in 2020. More recently, Okonofua et al. (2025) documented a national prevalence of 5.5%. These findings indicate that DM is an increasingly significant endocrinological disorder in Nigeria.The primary factors contributing to this increase include population aging, urbanization, sedentary lifestyles, unhealthy dietary patterns, and higher obesity rates.

Diagnosis of DM is primarily based on blood glucose measurements. Fasting blood glucose (FBG) is assessed after an overnight fast. Random blood glucose is taken at any time. The two-hour postprandial (2HPP) test evaluates glucose levels two hours after a meal. The oral glucose tolerance test (OGTT) is a first-line assessment in clinical settings. It involves administering a standardized glucose load and monitoring plasma glucose at set intervals to assess glycemic response (Darden et al., 2020; Makriset al., 2024). Glycated hemoglobin (HbA1c) is used widely to monitor long-term glycemic control.

DM is linked to debilitating complications. These include cardiovascular disease, nephropathy, neuropathy, and retinopathy. Such complications diminish quality of life and create substantial economic burdens for individuals and healthcare systems (Almalki & Khan, 2025). Diabetic nephropathy (DN) is a leading cause of chronic kidney disease (CKD) and end-stage renal disease (ESRD). It is a major microvascular complication of longstanding diabetes (Suneja et al., 2021). DN develops gradually and is marked by distinct renal biochemical changes, such as arly hyperfiltration. Microalbuminuria, altered serum creatinine and urea levels, electrolyte imbalances, and dysregulation of biomarkers like cystatin C and neutrophil gelatinase–associated lipocalin (NGAL) are observed (Gallo et al., 2023).

Early detection of renal impairment in diabetes is critical. Clinical symptoms often do not appear until after most nephrons are lost (Alkhaqani et al., 2022). Renal biochemical markers help detect subtle functional changes before overt kidney disease develops (Mizdrak et al., 2022). These include serum creatinine, urea, estimated glomerular filtration rate (eGFR), cystatin C, and urinary

albumin excretion. Microalbuminuria is the earliest known indicator of diabetic nephropathy (Thipsawa et al.,2021). Interpreting these biomarkers along with electrolyte profiles and other renal function measures enables a thorough assessment. This supports timely interventions to slow or prevent disease progression.

The increasing global prevalence of DM, combined with the frequently asymptomatic onset of renal impairment, highlights the necessity of early detection to prevent irreversible kidney complications. Effective intervention depends on regular biochemical monitoring and equitable access to healthcare services.

This study evaluates urea and creatinine levels in individuals with diabetes mellitus (DM) receiving treatment in referral hospitals in Enugu metropolis and examines their correlation with fasting plasma glucose to determine clinical relevance. Focusing on a Nigerian population, the research aims to generate context-specific evidence to inform early detection, monitoring, and intervention strategies for diabetic nephropathy. The anticipated findings will inform clinicians and policymakers in improving renal surveillance protocols and preventing diabetes-related renal complications

.

MATERIALS AND METHOD

Study Area/Design

This study utilized a cross-sectional survey design conducted in Enugu, a city in southeast Nigeria situated at the base of the Udi plateau. Enugu had a population of 722,664 and an area of 556 square kilometers as of the National Population Commission (NPC, 2006). The population mainly comprises civil servants and traders (Obianyido et al., 2023). The study population consisted of patients attending the diabetic clinic at Enugu State University of Science and Technology Teaching Hospital (ESUTH), Parklane, Enugu.

Study Population

One hundred and sixty respondents aged 30 to 65 years, matched for age and sex, were recruited for this study. Of these, eighty participants diagnosed with diabetes were assigned to the test group, and eighty healthy non-diabetic participants were assigned to the control group. All participants met the inclusion criteria and gave written informed consent.

Eligibility criteria

Case participants were required to have a confirmed diagnosis of Type 2 Diabetes Mellitus for at least one year, to be attending the diabetic clinic for routine follow-up, and not to be receiving dialysis or nephroprotective therapy. Control participants were eligible if they had no history of diabetes, hypertension, or renal disease, had not experienced recent acute illnesses or chronic diseases, and had not taken medications affecting renal function within the past six months. All respondents provided written informed consent.

Sample size determination and Sampling technique

The sample size was calculated using the formula for determining sample size in cross-sectional studies as described by Naing et al. (2022). The prevalence of Diabetes in southeast Nigeria is 3.7% (Adeloye et al., 2017). Respondents were selected using simple random sampling methiod, every 3rd individual who gave a written informed consent was interviewed and selected

Blood sample collection and Laboratory methods

Participants were instructed to fast overnight, abstaining from all food and beverages for 10 to 12 hours following their last evening meal. Blood samples were collected the next morning. The antecubital fossa was cleaned with methylated spirit swabs, and a tourniquet was applied to aid venipuncture. A total of 4 milliliters (mL) of venous blood was collected using a sterile syringe. Of this volume, 1 mL was transferred to a fluoride oxalate tube for fasting blood glucose measurement, while 3 mL was placed in a plain tube for the determination of urea and creatinine levels. The sample in the plain tube was allowed to clot, then centrifuged at 4000 revolutions per minute for 5 minutes. The separated serum was transferred to labeled containers and stored at 2 to 4 degrees Celsius. All analyses were performed within 48 hours. Fasting blood glucose level was estimated by the glucose oxidase method, serum creatinine level was assessed using the modified Jaffe method (Moore and Sharer, 2017), while urea was measured using the Diacetyl Monoxime (DAM) method (Langenfeld et al., 2021).

Statistical data analysis

Data management involved Microsoft Excel 2016, followed by export to GraphPad Prism version 8.0 (GraphPad Software Inc., USA) for statistical analysis. Normality of the data were assessed. Continuous variables were presented as mean ± standard deviation, and categorical variables as frequencies and percentages. Continuous variables were analyzed with Student's t-test while the chi-square test assessed categorical variables. Relationship between fasting plasma glucose and renal parameters were evaluated using Pearson correlation coefficients, as appropriate. Statistical significance was set at $p < 0.05$.

RESULTS

Table 1: Sociodemographic Characteristics of Study Participants

Parameters	Diabetics n(%)	Non -Diabetics n(%)	p-value
SEX			**<0.999**
Males	**40(50)**	**40(50)**	
Females	**40(50)**	**40(50)**	
Age(years)			**0.154**
30-39	**10(12.50)**	**13(16.25)**	
40-49	**26(13.50)**	**30(37.50)**	
50-59	**33(41.25)**	**34(42.50)**	
≥60	**11(13.75)**	**03(3.75)**	
Academic attainment			**0.042***
Completed primary School	**00(00)**	**01(1.25)**	
Completed primary School	**34(42.50)**	**48(60.00)**	
Completed primary School	**46(57.50)**	**31(38.75)**	
Marital Status			**0.741**
Living with a partner	**27(33.75)**	**30(37.50)**	
Living without a partner	**53(66.25)**	**50(62.50)**	

Table 1; summarizes the sociodemographic characteristics of 160 participants, including 80 individuals with type 2 diabetes and 80 non-diabetic controls. Both groups exhibited identical sex distributions, with equal representation of males and females (50.0% each). No statistically significant difference in sex distribution was identified between groups ($p > 0.999$).

The majority of participants in both groups were aged 50–59 years (41.3% of diabetics and 42.5% of controls), followed by those aged 40–49 years. A higher proportion of diabetics were aged 60 years or older compared to controls (13.8% versus 3.8%). However, the overall age distribution did not differ significantly between groups ($p = 0.154$).

Educational attainment differed significantly between groups ($p = 0.042$). A higher proportion of controls completed secondary-level education (60.0%) compared to diabetics (42.5%). Conversely, a greater percentage of diabetics attained higher education (57.5%) than controls (38.8%). Only one control participant reported primary education as the highest qualification.

Most respondents in both groups were not living with a partner (66.3% of diabetics and 62.5% of controls). No statistically significant difference in marital status was observed between groups ($p = 0.741$).

Table 2: Comparison of the biochemical parameters of the study participants

Parameters	Diabetics	Non-diabetics	p-value
Fasting Plasma glucose(mgdl)	**113.7.40±15.78**	**78.57±10.33**	**<0.0001*** **
Creatinine (mg/L)	**1.40±0.34**	**0.83±0.18**	**<0.0001*** **
Urea (mmol/L)	**7.79±1.78**	**4.03±0.53**	**<0.0001*** **

Table 2; compares fasting plasma glucose and renal function markers in diabetic and non-diabetic participants. Fasting plasma glucose was significantly higher in the diabetic group (109.40 ± 15.78 mg/dL) than in non-diabetic controls (78.57 ± 10.33 mg/dL), with a highly significant difference ($p < 0.0001$).

Serum creatinine levels were markedly elevated in diabetic participants (1.40 ± 0.34 mg/L) compared to non-diabetic participants (0.83 ± 0.18 mg/L), indicating impaired renal function ($p < 0.0001$). Mean serum urea concentration was also more than double in the diabetic group (7.79 ± 1.78 mmol/L) compared to controls (4.03 ± 0.53 mmol/L), with a statistically significant difference ($p < 0.0001$).

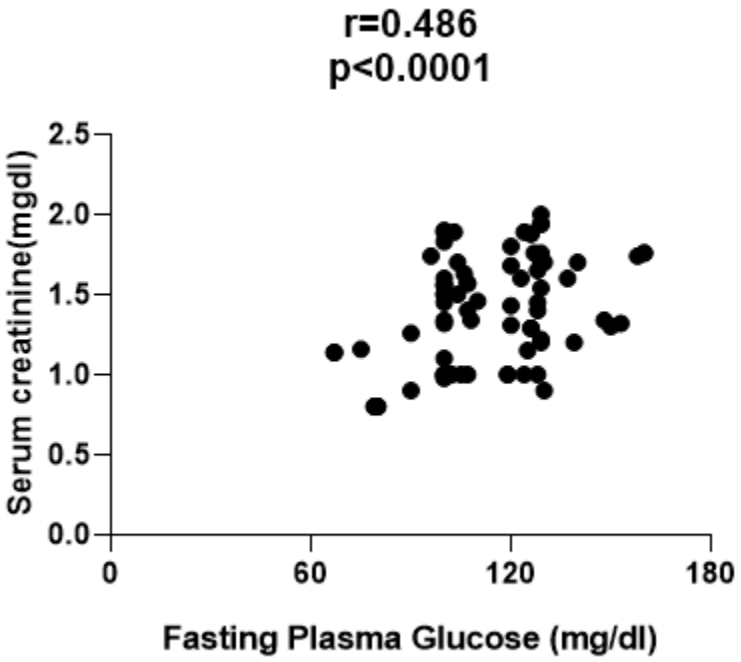

Fig1. Correlation Between Fasting Plasma Glucose and Serum Creatinine

A significant positive correlation($r = 0.486$, $p < 0.0001$) was observed between fasting plasma glucose and serum creatinine levels among diabetic participants, as illustrated in Figure 1.

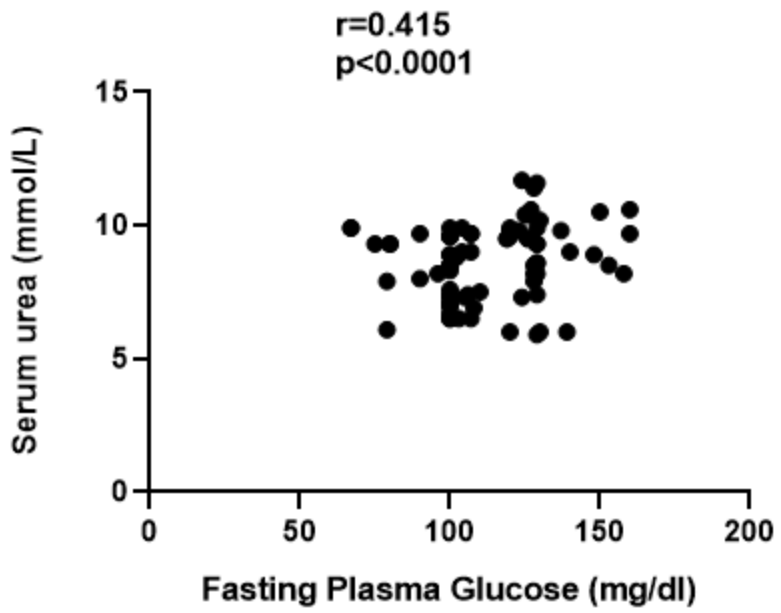

Fig2. Correlation Between Fasting Plasma Glucose and Serum urea

A significant positive correlation ($r = 0.415$, $p < 0.0001$) was observed between fasting plasma glucose and serum urea levels among diabetic participants, as illustrated in Figure 2.

DISCUSSION

The present study assessed serum urea and creatinine concentrations and examined their correlation with fasting plasma glucose in individuals with type 2 diabetes mellitus attending referral hospitals in Enugu metropolis, in order to clarify the clinical significance of renal function alterations in diabetes. Fasting plasma glucose concentrations were significantly higher in the diabetic cohort compared to non-diabetic controls. This observation is consistent with previous findings. Persistent hyperglycemia accelerates renal injury through several biochemical mechanisms. Elevated glucose levels facilitate the formation and accumulation of advanced glycation end products (AGEs). These contribute to both structural and functional deterioration of renal tissue (Wu et al., 2023). Four principal pathogenic pathways are implicated in hyperglycemia-induced diabetic nephropathy. They include activation of the polyol pathway, the hexosamine biosynthetic pathway, increased AGE formation, and protein kinase C (PKC) activation (Pirola et al.,2010). These mechanisms disrupt cellular homeostasis, increase oxidative stress, and promote glomerular sclerosis. This underscores the central role of chronic hyperglycemia in the development and progression of diabetic renal complications.

Diabetic participants exhibited significantly higher creatinine and urea levels compared to non-diabetic controls. These results are consistent with previous studies (Bamanik et al.,2016; Liu et al.,2022; Ullah et al.,2023; Akpotaire et al., 2023). Hyperglycemia induces renal hyperfiltration, which directly leads to both microvascular and macrovascular alterations. These vascular changes, in turn, cause an elevated glomerular filtration rate (GFR), resulting in increased serum urea and creatinine concentrations (Ceriket al., 2023). This underscores the well-documented phenomenon that diabetic nephropathy often progresses subclinically before overt symptoms emerge (Podadera-Herreros et al.,). In settings with limited resources, where advanced markers such as microalbuminuria are not routinely available, serum urea and creatinine serve as practical and cost-effective screening tools. Routine biochemical monitoring may facilitate early intervention and reduce the risk of progression to chronic kidney disease or end-stage renal failure.

Positive correlations between fasting plasma glucose and serum creatinine demonstrate that poor glycemic control is closely associated with declining renal function in individuals with type 2 diabetes. This observation is consistent with previous research (Bamanika et al., 2016, Liu et al., 2022, Ullah et al., 2023 Akpotaire et al., 2023). Collectively, these findings indicate that elevated blood glucose levels may initiate renal dysfunction prior to the clinical manifestation of kidney disease.

The sociodemographic characteristics of the study population indicate that diabetic and non-diabetic groups were comparable in sex distribution, minimizing potential gender-related bias in the comparative analysis. While age differences were not statistically significant, most individuals with diabetes were middle-aged or older adults, supporting the established association between aging and type 2 diabetes (Nanayakkara et al.,2021). A significant difference in educational attainment was observed, with non-diabetic participants more frequently completing secondary education. This finding implies that higher educational levels may provide protective benefits through increased health literacy and engagement in preventive behaviors (Almachavan, 2024). Relationship status did not differ significantly between groups. However, the high proportion of participants not cohabiting with a partner in both groups may indicate limited social support, which could affect long-term disease management. These results highlight the need to incorporate targeted health education and age-specific renal screening into diabetes care programs.

CONCLUSION

Elevated serum creatinine and urea levels observed in patients with type 2 diabetes mellitus (T2DM), along with their positive correlation with fasting plasma glucose (FPG), suggest a risk of renal impairment. Although these markers are not the most sensitive indicators of early dysfunction, their rise may reflect emerging subclinical kidney injury associated with poor glycemic control. Sociodemographic factors such as lower educational attainment could further contribute to disease progression by reducing health literacy and poor adherence to management strategies. Regular monitoring of renal function, improved glycemic control, and patient-centered

education are crucial to prevent the onset and progression of chronic kidney disease, especially among middle-aged and older adults with T2DM.

Ethical Approval

The study was reviewed and approved by the Ethical Committee of the ESUTH Teaching Hospital in Enugu (ESUTHP/C-MACRA/034/VOL.4/98). All procedures used in this study adhered to the guidelines outlined in the 1964 Declaration of Helsinki. Participant's confidentiality was ensured.

CONSENT

As per international standards or university standards, patient(s) written consent has been collected and preserved by the author(s)

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

REFERENCES

Adeloye D, Ige JO, Aderemi AV, Adeleye N, Amoo EO, Auta A et al.(2017). Estimating the prevalence,hospitalization and mortality from type 2 diabetes mellitus in Nigeria: a systematic review and meta-analysis. BMJ Open;7(5): e015424.

Akpotaire P, Seriki S. Assessment and correlation of serum urea and creatinine levels in normal, hypertensive, and diabetic persons in Auchi, Nigeria. Clin Res. 2023;7:007-16.

Alkhaqani AL. Risk Factors and Complications of Chronic Kidney Disease: Narrative Review. Al-Rafidain Journal of Medical Sciences (ISSN 2789-3219). 2022 Jun 20;2:107-14.

Almachavan SA. The role of health literacy in enhancing preventive healthcare: A comprehensive review of challenges, interventions, and future directions. Journal of Research in Clinical Medicine. 2024 Dec 15;12(1):36-.

Almalki, W. H., & Khan, M. S. (2025). Burden of diabetes mellitus on health and economy of the Arab world: current situation and perspectives. Journal of Public Health, 1-20.

Bamanikar SA, Bamanikar AA, Arora A. Study of Serum urea and Creatinine in Diabetic and nondiabetic patients in a tertiary teaching hospital. The Journal of Medical Research. 2016 Jan;2(1):12-5.

Banday, M. Z., Sameer, A. S., & Nissar, S. (2020). Pathophysiology of diabetes: An overview. Avicenna Journal of Medicine, 10(4), 174. https://doi.org/10.4103/ajm.ajm_53_20

Cerik I, Dindaş F, YILMAZ M. Remember Diabetes Mellitus When Assessing Renal Blood Flow in Hypertensive Patients: a Renal Frame Count Study. Türk Kardiyoloji Derneği Arşivi. 2023;51(1).

Darden, C. M., Farrow, A. E., Rajan, S. K., Lakhani, M., Lawrence, M. C., & Naziruddin, B. (2020). Predicting the function of islets after transplantation. In Transplantation, Bioengineering, and Regeneration of the Endocrine Pancreas (pp. 547-561). Academic Press.

Ezeani IU, Chukwuonye II, Onyeonoro UU, Chuku A, Ogah OS. Prevalence and risk factors for diabetes mellitus in a state in South East Nigeria: Results of a population based house to house survey. Current diabetes reviews. 2020 Feb 1;16(2):181-7.

Gallo, G., Lanza, O., & Savoia, C. (2023). New insight in cardiorenal syndrome: from biomarkers to therapy. International Journal of Molecular Sciences, 24(6), 508

Hoogeveen EK. The epidemiology of diabetic kidney disease. Kidney and Dialysis. 2022 Aug 1;2(3):433-42.

Hossain MJ, Al-Mamun M, Islam MR. Diabetes mellitus, the fastest growing global public health concern: Early detection should be focused. Health Science Reports. 2024 Mar;7(3):e2004.

International Diabetes Federation (IDF). (2021). IDF Diabetes Atlas, 10th edition. https://diabetesatlas.org

Langenfeld NJ, Payne LE, Bugbee B. Colorimetric determination of urea using diacetyl monoxime with strong acids. PLoS One. 2021 Nov 8;16(11):e0259760.

Liu J, Pan Y, Yan Z, Jiang H, Li H, Yu Y. Global, regional, and national burden of Chronic kidney disease due to type 2 diabetes mellitus, 1990-2021, with forecasts to 2050: a forecasting study for the Global Burden of Disease Study 2021.

Liu X, Du H, Sun Y, Shao L. Role of abnormal energy metabolism in the progression of chronic kidney disease and drug intervention. Renal failure. 2022 Dec 31;44(1):790-805.

Makris, K., Spanou, L., Papanas, N., Kotsa, K., & Christodoulou, M. (2023). Emerging biomarkers of diabetic nephropathy: New tools for risk stratification. Journal of Clinical Medicine, 12(4), 982. https://doi.org/10.3390/jcm12040982

Mizdrak M, Kumrić M, Kurir TT, Božić J. Emerging biomarkers for early detection of chronic kidney disease. Journal of personalized medicine. 2022 Mar 31;12(4):548.

Moore, J. F., & Sharer, J. D. (2017). Methods for quantitative creatinine determination. Current protocols in human genetics, 93(1), A-3O.

Naing, L., Nordin, R.B., Abdul Rahman, H., Naing. Y. T (2022). Sample size calculation for prevalence studies using Scalex and ScalaR calculators. BMC Med Res Methodol 22(209).

Nanayakkara N, Curtis AJ, Heritier S, Gadowski AM, Pavkov ME, Kenealy T, Owens DR, Thomas RL, Song S, Wong J, Chan JC. Impact of age at type 2 diabetes mellitus diagnosis on mortality and vascular complications: systematic review and meta-analyses. Diabetologia. 2021 Feb;64(2):275-87.

Obianyido O H, Ebere OO, Raluchukwu OC. Comparative Analysis of High-Sensitivity C-Reactive Protein and Plasma Fasting Glucose Levels in Type 2 Diabetic Adults on Treatment and Non-Diabetic Adults in Enugu Metropolis. International Journal of Biochemistry Research & Review. 2025 Sep 2;34(5):64-71.

Obianyido OE, Obianyido HO, Imosemi RE. Potential Health Risk Evaluation of Heavy Metal Exposure from Consuming Commercially Produced Food Seasonings in Enugu, Nigeria. European Journal of Nutrition and Food Safety. 2023 Aug 30;15(9):33-41.

Okonofua F, Ntoimo LF, Ogu R, Isikhuemen M. Public Policy and Health System Responses to Diabetes Mellitus in Nigeria: A Call for Reform. Health Systems & Reform. 2025 Dec 31;11(1):2477941.

Pirola, L.; Balcerczyk, A.; Okabe, J.; El-Osta, A. Epigenetic phenomena linked to diabetic complications. Nat. Rev. Endocrinol. 2010, 6, 665–675.

Podadera-Herreros A. Influence of obesity on the evolution of diabetic nephropathy: consumption of two heart-healthy diet models as therapeutic strategy in disease development.

Shaikhomer M. Epidemiology and Clinical Advancements in Managing and Treating Diabetes Mellitus. Pakistan Journal of Life & Social Sciences. 2025 Jan 1;23(1).

Siddiqui K, George TP, Joy SS, Alfadda AA. Risk factors of chronic kidney disease among type 2 diabetic patients with longer duration of diabetes. Frontiers in Endocrinology. 2022 Dec 9;13:1079725.

Suneja, M. (2021). Diabetic nephropathy and diabetic kidney disease. Journal of diabetes mellitus, 11(5), 359-377.

Thipsawat S. Early detection of diabetic nephropathy in patient with type 2 diabetes mellitus: A review of the literature. Diabetes and Vascular Disease Research. 2021 Nov 9;18(6):14791641211058856.

Ullah W, Nazir A, Israr H, Hussain S, Farooq M. Assessment of serum urea and creatinine levels in diabetic patients. BioScientific Review. 2023 Oct 3;5(3):26-32.

World Health Organization (WHO). (2022). Diabetes Country Profiles 2022: Nigeria. https://www.who.int/diabetes/country-profiles/nga_en.pdf

Wu T, Ding L, Andoh V, Zhang J, Chen L. The mechanism of hyperglycemia-induced renal cell injury in diabetic nephropathy disease: an update. Life. 2023 Feb 15;13(2):539.