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ASSESSING THE IMPACT OF GLYCAEMIC CONTROL ON LIVER FUNCTION IN TYPE 2 DIABETES: A CROSS-SECTIONAL RETROSPECTIVE ANALYSIS OF LIVER CHEMISTRIES

Londeka Nontobeko Ndaba, Ziningi Nobuhle Jaya, Nokukhanya Thembane*
Department of Biomedical Sciences, Faculty of Applied and Health Science, Mangosuthu University of Technology, South Africa, Durban

Abstract

Objective

This study investigates the relationship between liver biomarkers and glycaemic control in Type 2 Diabetes Mellitus (T2DM) patients at King Edward Hospital, KwaZulu-Natal, South Africa.

Methods

A retrospective, cross-sectional study was conducted on 80 patients diagnosed with T2DM. Data collected included gender distribution, age range, glycaemic control (HbA1c, fasting glucose, and random glucose), and liver function markers (bilirubin, ALT, AST, and GGT). The study period ranged from June 2023 to December 2023. Patients were evaluated for glycaemic control and liver biomarkers, and statistical analysis was performed to explore correlations between these factors.

Results

The majority of patients (57.5%) were aged 46-65, with an emerging trend of younger patients being diagnosed with T2DM. A significant gender disparity was observed, with females comprising 83.8% of the study population. All participants exhibited HbA1c levels in the diabetic range (≥6.5%), indicating poor glycaemic control. A notable proportion of patients showed elevated liver enzymes: 35.7% had mildly elevated ALT levels, 29.6% had elevated AST levels, and 75.2% had abnormal GGT levels. Positive and significant correlations were found between HbA1c and liver enzymes: HbA1c and ALT ($r = 0.43$, $p < 0.01$), HbA1c and AST ($r = 0.51$, $p < 0.01$), and HbA1c and GGT ($r = 0.61$, $p < 0.01$). These findings suggest that poor glycaemic control is strongly associated with liver dysfunction.

Conclusion

The results indicate a strong association between poor glycaemic control and elevated liver enzymes in T2DM patients, highlighting the need for comprehensive management strategies targeting both glycaemic control and liver health. Regular monitoring of liver biomarkers should be considered to facilitate early detection of liver dysfunction, potentially preventing severe liver-related complications.

Recommendations

Regular liver function monitoring should be integrated into diabetes management, particularly for the early detection of conditions like NAFLD. Improving glycaemic control is crucial to mitigate liver-related complications.

***Keywords**: Type 2 Diabetes Mellitus, liver biomarkers, Glycaemia Control, Non-Alcoholic Fatty Liver Disease, Glycated Hemoglobin, Alanine Transaminase, Aspartate Transaminase, Gamma-Glutamyl Transferase.*
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***Corresponding Author:** Nokukhanya Thembane*
***Email:** thembane@mut.ac.za*
Department of Biomedical Sciences, Faculty of Applied and Health Science, Mangosuthu University of Technology, South Africa, Durban

Background

Type 2 diabetes mellitus (T2DM) and non-alcoholic fatty liver disease (NAFLD) are intricately linked, with NAFLD affecting 60-80% of T2DM patients (Bril & Cusi, 2016). This bidirectional relationship is underpinned by insulin resistance, which is a hallmark of both conditions (Wan Mu et al., 2019). NAFLD, which can range from simple steatosis to more severe forms like non-alcoholic steatohepatitis (NASH), cirrhosis, and hepatocellular carcinoma, significantly complicates the clinical management of T2DM (Dharmalingam & Yamasandhi, 2018a; Wan Mu et al.., 2019). The liver plays a critical role in glucose and lipid metabolism, and its dysfunction in T2DM patients worsens the risk of further complications (Wan Mu et al., 2019). Early detection and management of NAFLD are crucial, with non-invasive assessment methods such as clinical scoring systems and transient elastography recommended for monitoring (Dharmalingam & Yamasandhi, 2018a). Effective treatment strategies are focused on improving insulin sensitivity and glycaemic control to mitigate the progression of liver dysfunction (Dharmalingam &

Yamasandhi, 2018a). Recent research highlights the need for a deeper understanding of the interplay between T2DM and liver-related outcomes to optimize management (Sanchez et al., 2023).

The liver is central to numerous physiological processes, including glucose metabolism, fat storage, and detoxification. In T2DM, liver dysfunction significantly worsens metabolic imbalances, increasing the risk of liver disease (Compean & Quintana, 2019). Approximately 30% of individuals with liver disease also have T2DM, with over 80% of these patients showing glucose intolerance (Compean & Quintana, 2019). NAFLD, often termed metabolic-associated fatty liver disease (NAFLD), is a common hepatic manifestation of T2DM and can progress to more severe stages such as NASH, cirrhosis, and hepatocellular carcinoma (Mohammed & Nafizah, 2016). This progression is closely linked to insulin resistance, a key characteristic of T2DM, which, along with obesity and dyslipidemia, creates a complex metabolic environment that accelerates liver damage (Lindenmeyer & McCullough, 2018). Chronic hyperglycemia and oxidative stress contribute to liver inflammation, further worsening hepatic function and creating a vicious cycle that worsens glucose metabolism, making it increasingly difficult to control blood glucose levels.

Globally, the prevalence of T2DM is on the rise, with approximately 463 million people affected worldwide, accounting for 90% of all diabetes cases (Saeedi et al., 2019). This surge in diabetes cases is accompanied by a growing burden of liver disease, driven by obesity and aging—two major risk factors contributing to the increasing incidence of T2DM (Chauke et al., 2023). This growing prevalence imposes a significant strain on healthcare systems, particularly in low- and middle-income countries, where the disease burden is still under-addressed (Ganju et al., 2020). In South Africa, there is limited research on the impact of T2DM on liver health, highlighting the need for further investigation in this area. Both T2DM and NAFLD are chronic, often asymptomatic conditions that contribute significantly to morbidity, mortality, and disability, placing immense pressure on healthcare systems and increasing financial burdens (Younossi, 2018). As the global prevalence of these conditions continues to rise, understanding the relationship between T2DM and liver dysfunction becomes critical for effective disease management.

The liver's role in maintaining homeostasis is essential, regulating plasma glucose levels, synthesizing hormones, and detoxifying the body (Hantzidiamantis et al., 2024). Liver function tests (LFTs), which measure enzymes such as ALT, AST, ALP, and GGT, as well as proteins like bilirubin and albumin, offer valuable insights into the liver's metabolic activity and its impact on peripheral circulation (Lala et al., 2023). In T2DM, liver dysfunction can accelerate the progression of the disease, with elevated levels of ALT, AST, and GGT indicative of liver damage or inflammation (Bertolini et al., 2022). While the relationship between liver dysfunction and T2DM is well-established, the exact nature of this link is still unclear. It is uncertain whether liver dysfunction is a cause or a consequence of T2DM or if the two conditions exacerbate each other in a bidirectional manner (Qadri & Yki-Järvinen, 2024). Additionally, factors such as age, gender, and lifestyle may influence this relationship, though their roles remain inadequately understood. Although liver complications in T2DM are increasingly recognized, the liver's role in diabetes progression and management remains underexplored (Arvanitakis et al., 2024).

T2DM is a major risk factor for liver disease and is associated with increased mortality in this patient population (Björkström et al., 2019). Liver diseases, including NAFLD and NASH, have emerged as significant causes of death in individuals with T2DM. However, there is still a significant gap in understanding the long-term changes in liver function in T2DM patients, particularly concerning liver chemistries over time. This gap hinders our understanding of how T2DM affects liver health and how diabetes management strategies influence liver function. As such, research investigating liver chemistries in T2DM patients over extended periods is essential to understanding liver disease progression in this cohort. This study aims to explore the relationship between liver function and glycaemic control in T2DM patients, focusing on the role of liver biomarkers (ALT, AST, ALP, GGT, bilirubin, albumin) in the progression of liver dysfunction and its impact on glycaemic control.

Methods

Study Design and Setting

This study employed a quantitative, retrospective, cross-sectional design to explore the relationship between glycaemic control and liver function in patients with T2DM. The research was conducted at the Clinical Laboratory of King Edward Hospital, part of the National Health Laboratory Services (NHLS), found in KwaZulu-Natal, Durban.

Study Population and Sampling Strategy

The study population consisted of male and female patients diagnosed with T2DM. Patient results included in the study were those between June 1, 2023, and December 31, 2023. Inclusion criteria required a confirmed diagnosis of T2DM, complete demographic and laboratory data, and laboratory results from the specified time. Patients were excluded if they were under 18 years of age, had incomplete or missing demographic and laboratory data, or did not have a confirmed diagnosis of Type 2 Diabetes Mellitus (T2DM).

Sample and Data Collection

Data for the study were retrospectively extracted from the NHLS Trakcare laboratory information system, which houses clinical and laboratory records. The data collected included patient demographics and laboratory results pertinent to liver function (e.g., ALT, AST, GGT, bilirubin, and albumin) and glycaemic control markers (e.g., HbA1c and fasting glucose). The sample size was estimated to be a minimum of 100 T2DM patient records

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to ensure adequate statistical power (80%) at a 5% significance level.

Ethical Considerations

Ethical approval for this study was obtained from the Mangosuthu University of Technology Ethics Review Committee on 19 February 2024 (RD5/25/2024), ensuring that all data was used according to ethical guidelines. Patient confidentiality was maintained throughout the study, with only anonymized data being accessed from the NHLS database.

Efforts to Address Potential Sources of Bias:

To minimize potential sources of bias, several strategies were implemented throughout the study. First, we ensured that only patients with complete demographic and laboratory data were included, reducing the risk of selection bias. Second, all laboratory tests were conducted by the Clinical Laboratory of King Edward Hospital, a single, standardized facility, to control for variations in testing procedures and ensure consistency in the results. Furthermore, we used a retrospective design, which allowed us to collect data from a large, diverse sample of patients, helping to enhance the generalizability of the findings. Lastly, the study was conducted using a clear set of inclusion and exclusion criteria, which helped reduce information bias and ensured a more homogenous study population. These steps were taken to ensure the validity and reliability of the results and minimize bias in the study.

Diabetes Status Definition

Diabetes status was determined based on laboratory values, with HbA1c ≥6.5% and/or fasting glucose ≥7.0 mmol/L, or a documented diagnosis of T2DM in patient records.

Data Variables

Key data variables included liver enzymes (ALT, AST, GGT) and glycaemic markers (HbA1c, fasting glucose). Liver enzymes were measured using automated analyzers, with ALT and AST analyzed by the kinetic method and GGT by the enzymatic method. Glycaemic markers were assessed via high-performance liquid chromatography (HPLC) for HbA1c and the hexokinase method for fasting glucose.

Data Analysis

The collected data were analyzed using statistical software, with descriptive statistics used to summarize the demographic and clinical characteristics of the study population. Statistical tests will be applied to examine the relationships between glycaemic control markers and liver enzyme levels.

Results

Gender Distribution

The study revealed a gender disparity, with a significantly higher proportion of female patients (83.8%) compared to male patients (16.2%). This observation is consistent with general trends where Type 2 diabetes tends to be more prevalent in females, particularly after menopause.

Table 1: Gender Distribution of Type 2 Diabetes Patients

Gender	Frequency	Percentage
Males	13	16.2%
Females	67	83.8%
Total	**80**	**100%**

Age Distribution

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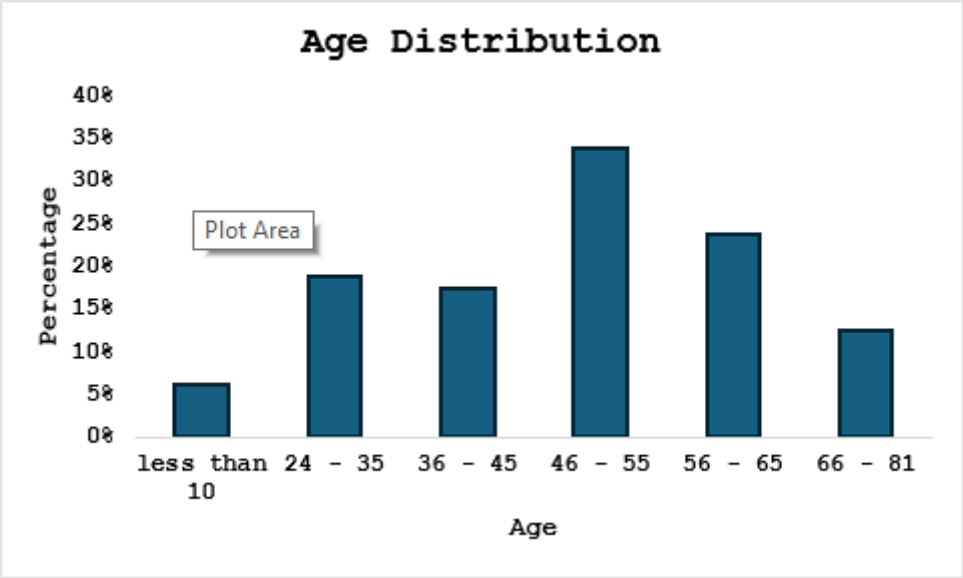

Figure 1: Most patients (57.5%) were in the 46-65 age range, consistent with established knowledge that Type 2 diabetes prevalence increases with age. However, the presence of younger patients (ages 7-11 and 24-35) indicates an emerging trend of diabetes in younger populations, likely influenced by rising obesity and sedentary lifestyles.

GLYCAEMIC CONTROL

All patients in this study had HbA1c values in the diabetes range (≥6.5%), with 100% falling within the diabetic range. This suggests poor glycemic control across the board, highlighting the need for enhanced diabetes management.

Table 2: Glucose Levels Classification for Diabetes Diagnosis

HbA1c Range	Frequency	Percentage
Normal (4.0–5.6%)	0	0%
Prediabetes (5.7–6.4%)	0	0%
Diabetes (≥6.5%)	93	100%

Similar to the HbA1c results, all patients had glucose levels indicating diabetes, as both fasting glucose (≥7.0 mmol/L) and random glucose (≥11.1 mmol/L) levels were elevated across the board.

Table 3: Glucose Levels Classification for Diabetes Diagnosis

Glucose Level Range	Frequency	Percentage
Normal (Fasting: 3.9–5.5 mmol/L, Random: <7.8 mmol/L)	0	0%
Prediabetes (Fasting: 5.6–6.9 mmol/L, Random: 7.8–11.0 mmol/L)	0	0%
Diabetes (Fasting: ≥7.0 mmol/L, Random: ≥11.1 mmol/L)	93	100%

Distribution of HbA1c Levels and Glycaemic Control in the Study Population

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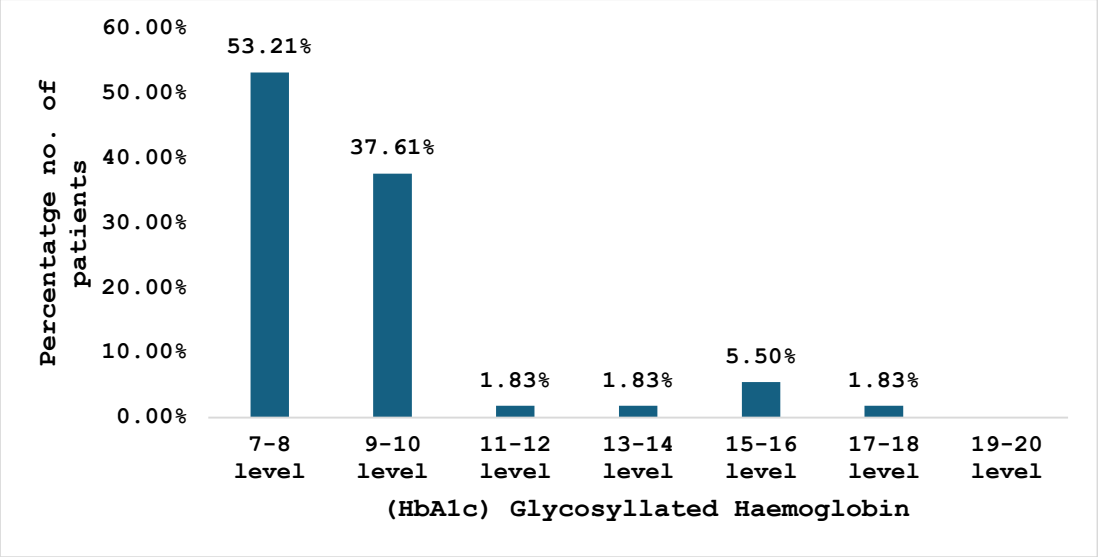

Figure 2: Frequency of elevated HbA1c levels in the study population.

The distribution of HbA1c levels among the study population revealed a varied range of glycaemic control. The majority of patients (53.21%) had HbA1c levels between 7-8%, indicating fair glycaemic control. However, a significant proportion (37.61%) had HbA1c levels between 9-10%, suggesting poor glycaemic control. A smaller percentage of patients had HbA1c levels above 10%, with 1.83% in the 11-12% range, 1.83% in the 13-14% range, 5.50% in the 15-16% range, and 1.83% in the 17-18% range.

LIVER FUNCTION MARKERS

The study also assessed liver function markers, including total bilirubin, ALT (alanine transaminase), AST (aspartate transaminase), and GGT (gamma-glutamyl transferase), which are essential for understanding the relationship between liver dysfunction and diabetes.

Distribution of Total Bilirubin Levels

Most patients (63.51%) had normal total bilirubin levels, but a portion of the population (8.11%) exhibited mildly elevated levels, which could suggest early liver stress or non-alcoholic fatty liver disease (NAFLD), a common comorbidity in T2DM.

Table 4: Distribution of Total Bilirubin Levels in the Study Population and Implications for Liver Health

Bilirubin Level	Frequency	Percentage
Normal (5.1–17.1 µmol/L)	47	63.51%
Mildly Elevated (17.2–30 µmol/L)	6	8.11%
Moderately Elevated (30.1–60 µmol/L)	2	2.70%
Severely Elevated (>60 µmol/L)	2	2.70%

LIVER ENZYMES

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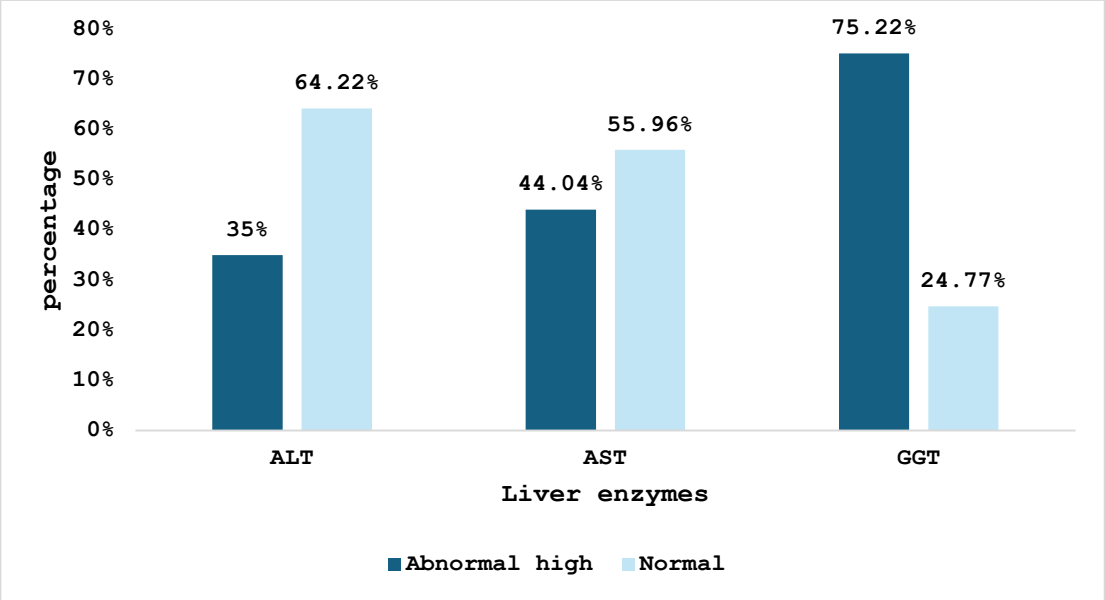

Figure 3: Comparison of aspartate aminotransferase, alanine aminotransferase, and gamma-glutamyl transferase.

The distribution of liver enzyme levels among the study population revealed notable abnormalities, with 35% of patients showing abnormally high ALT levels, while 64.22% had normal levels. Similarly, AST levels were abnormal in 44.04% of patients, whereas 55.96% had normal levels. Most strikingly, GGT levels were abnormal in a substantial 75.22% of patients, with only 24.77% having normal levels, collectively indicating a significant proportion of patients with liver enzyme abnormalities, suggesting potential liver damage or dysfunction.

ALT (Alanine Transaminase)

A significant portion of patients (35.71%) showed mildly elevated ALT levels, which may indicate liver inflammation or early liver disease, including NAFLD.

Table 6: Distribution of ALT Levels

ALT Level (U/L)	Frequency	Percentage
Normal (10–40 U/L)	31	31.68%
Mildly Elevated (41–120 U/L)	35	35.71%
Moderately Elevated (121–300 U/L)	16	16.16%
Severely Elevated (>300 U/L)	4	4.04%

AST (Aspartate Transaminase)

Elevated AST levels were observed in a significant number of patients, with 29.63% having mildly elevated levels. This supports the notion that Type 2 diabetes patients may experience concurrent liver injury, as both AST and ALT levels are commonly elevated in liver dysfunction.

Table 7: Distribution of AST Levels

AST Level (U/L)	Frequency	Percentage
Normal (10–40 U/L)	17	31.48%
Mildly Elevated (41–120 U/L)	16	29.63%
Moderately Elevated (121–300 U/L)	10	18.52%
Severely Elevated (>300 U/L)	3	5.56%

GGT (Gamma-Glutamyl Transferase)

A substantial percentage of patients (28.2%) had elevated GGT levels, with some showing severe elevations, which could indicate liver dysfunction, possibly linked to the metabolic disturbances of Type 2 diabetes.

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Table 8: Distribution of GGT (Gamma-Glutamyl Transferase) Levels

GGT Level (U/L)	Frequency	Percentage
Normal (0–50 U/L)	21	16.42%
Mildly Elevated (51–100 U/L)	13	10.16%
Moderately Elevated (101–200 U/L)	11	8.59%
Severely Elevated (>200 U/L)	12	9.45%

ESTABLISHING CORRELATIONS

Correlation Between HbA1c and Liver Enzymes: Correlation Coefficients

The study found significant positive correlations between HbA1c and liver enzymes (ALT, AST, GGT), indicating a strong association between poor glycaemic control and liver dysfunction.

The correlation coefficients were as follows:

- HbA1c and ALT ($r = 0.43$, $p < 0.01$)
- HbA1c and AST ($r = 0.51$, $p < 0.01$)
- HbA1c and GGT ($r = 0.61$, $p < 0.01$)

This suggests that poor glycaemic control is associated with liver damage or inflammation and that these liver enzyme levels are strongly correlated.

Table 9: Correlation Between HbA1c and Liver Enzymes (ALT, AST, GGT)

HbA1c	ALT	AST	GGT
1	0.43	0.51	0.61
0.43	1	0.65	0.71
0.51	0.65	1	0.75
0.61	0.71	0.75	1

DISCUSSION AND ANALYSIS OF FINDINGS

Gender Distribution

The gender distribution revealed a notable predominance of female patients (83.8%) compared to male patients (16.2%). This finding is consistent with global and regional trends showing a higher prevalence of T2DM in females, particularly after menopause (Kautzky-Willer et al., 2023). Hormonal changes, especially the reduction in oestrogen levels after menopause, contribute to increased adiposity, insulin resistance, and a higher risk of developing T2DM in women (Motlani et al., 2023). Additionally, studies by Ciarambino et al. (2022) and Alrashed et al. (2024) emphasize gender differences in T2DM pathophysiology, supporting the notion that females are more susceptible to developing diabetes due to metabolic and hormonal factors.

Age Range Distribution

The majority of patients (57.5%) were in the 46-65 age range, aligning with the established literature that T2DM prevalence increases with age (Magliano and Boyko, 2021). Aging is associated with declining insulin sensitivity, a hallmark of T2DM (Kolb et al., 2023). However, the presence of younger patients in the 7-11 and 24-35 age ranges, though representing smaller proportions, reflects an emerging trend of T2DM in younger populations. This could be attributed to rising obesity rates, poor dietary habits, and sedentary lifestyles, all contributing to the increasing incidence of T2DM among younger individuals (Pappachan et al., 2024). These findings emphasize the urgent need for preventive strategies targeting younger populations, particularly in regions experiencing increasing rates of childhood obesity.

Glycaemic Control

The study's findings regarding HbA1c levels were concerning, as 100% of patients had HbA1c values in the diabetes range (≥6.5%), indicating poor glycaemic control. This aligns with a substantial body of literature suggesting poor glycaemic control is common among individuals with T2DM (Yahaya et al., 2023). Elevated HbA1c levels, a key marker for long-term glycaemic control, are associated with an increased risk of diabetes-related complications, including cardiovascular disease, nephropathy, and neuropathy (Sartore et al., 2023). These results highlight the need for more aggressive diabetes management strategies, as chronic hyperglycaemia can lead to irreversible organ damage and significantly increase healthcare costs.

LIVER FUNCTION MARKERS

This study evaluated liver function markers (bilirubin, ALT, AST, and GGT), which are crucial for understanding liver dysfunction in T2DM patients.

Total Bilirubin Levels

A substantial portion of patients (63.51%) had normal bilirubin levels, indicating no apparent liver dysfunction. However, a small group (8.11%) exhibited mildly elevated bilirubin levels, which may suggest early liver stress. This finding is consistent with studies indicating that liver abnormalities, particularly NAFLD, are common in T2DM patients (Hazlehurst et al., 2016). NAFLD, often linked to insulin resistance and obesity, is frequently undiagnosed in T2DM patients but can progress to more severe liver diseases (Dharmalingam and Yamasandhi et al., 2018b).

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ALT and AST Levels

A significant proportion of patients showed mildly elevated ALT (35.71%) and AST (29.63%) levels. Elevated ALT and AST are indicative of liver inflammation or damage, frequently seen in T2DM due to NAFLD or NASH (Mandal et al., 2018). ALT is more specific to liver damage than AST, which can also rise due to muscle injury (Lala et al., 2023). These findings align with Mandal et al. (2018), who found elevated liver enzymes in T2DM patients, emphasizing the need for routine liver function monitoring in this population.

GGT Levels

A considerable percentage of patients (28.2%) had elevated GGT levels, some of which were severely elevated. GGT is associated with oxidative stress and liver dysfunction and is frequently elevated in individuals with metabolic syndrome and T2DM (Kwak et al., 2023). Elevated GGT levels are well-documented as an early marker of liver dysfunction and insulin resistance (Kwak et al., 2023; Lee et al., 2013). The presence of severely elevated GGT levels in some patients is concerning and highlights the need for early identification and intervention to prevent the progression of liver disease.

Correlation Between HbA1c and Liver Enzymes

A significant finding in this study is the positive correlations between HbA1c and liver enzymes, including ALT ($r = 0.43$, $p < 0.01$), AST ($r = 0.51$, $p < 0.01$), and GGT ($r = 0.61$, $p < 0.01$). These strong associations suggest that poor glycaemic control contributes to liver dysfunction, supporting the idea that elevated liver enzymes may reflect the extent of metabolic disturbances in T2DM patients. The higher correlation between HbA1c and GGT ($r = 0.61$) is particularly noteworthy as it suggests that GGT may be a sensitive early marker for both liver dysfunction and insulin resistance. These findings are consistent with studies indicating that hyperglycaemia promotes liver damage through mechanisms such as insulin resistance and oxidative stress (Abebe et al., 2022). Monitoring both glycaemic control and liver function is critical in preventing severe liver complications in T2DM patients.

Mechanisms Linking Poor Glycaemic Control and Liver Dysfunction in Type 2 Diabetes Mellitus

The foregoing work findings suggest a significant association between poor glycaemic control and liver dysfunction in T2DM patients. A key mechanism is insulin resistance, which contributes to fat accumulation in the liver and the development of NAFLD (Nogueira and Cusi, 2024). Chronic hyperglycaemia leads to oxidative stress, exacerbating hepatic inflammation and cellular damage (Caturano et al., 2023). Systemic inflammation, driven by metabolic syndrome and increased adiposity, further contributes to both insulin resistance and liver injury (Rohm et al., 2022). In postmenopausal women, hormonal changes exacerbate insulin resistance and visceral adiposity, increasing the risk of liver dysfunction (Ko and Kim, 2020). These mechanisms create a feedback loop where poor glycaemic control worsens liver function, and liver dysfunction further impairs glucose metabolism. This highlights the importance of integrated management strategies for both glycaemic control and liver health in T2DM patients.

Conclusion

This study adds to the existing research in KwaZulu-Natal, which has shown that diabetic patients exhibit significant lipid abnormalities (Madlala and Thembane, 2023). In addition to these findings, this study highlights the relationship between poor glycaemic control and liver dysfunction in T2DM patients, as indicated by elevated liver enzymes (ALT, AST, GGT) and bilirubin levels. These results emphasize the complex interplay between glycaemic control and liver health in diabetic patients. Comprehensive management strategies should address both glycaemic control and liver dysfunction to reduce the risk of cardiovascular and liver-related complications in T2DM patients. Early detection and regular monitoring of liver function and lipid profiles are essential to improving patient outcomes.

Study Limitations and Generalizability

This study has several limitations. Although the sample size was adequate for preliminary analysis, it may limit the generalizability of the findings. The retrospective nature of the study restricted access to detailed data on lifestyle factors and medical histories, which could have provided deeper insights into potential confounders. Furthermore, the exclusion of patients with incomplete or missing data may have introduced selection bias, potentially affecting the representativeness of the sample. These factors should be considered when interpreting the results. A prospective study with a larger sample size and comprehensive data collection could provide more robust and generalizable conclusions.

Recommendations and Future Research

This study emphasizes the link between poor glycaemic control and liver dysfunction in T2DM patients. Regular liver function monitoring should be integrated into diabetes management, particularly for the early detection of conditions like NAFLD. Improving glycaemic control is crucial to mitigate liver-related complications. Future research should focus on long-term studies to further explore the impact of chronic hyperglycaemia on liver function and investigate the mechanisms driving liver damage in T2DM. Research into integrated interventions targeting both metabolic control and liver health could enhance patient outcomes, particularly in high-risk groups, such as postmenopausal women and younger individuals.

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Abbreviation Full Form
ALT Alanine Transaminase
AST Aspartate Transaminase
GGT Gamma-Glutamyl Transferase
HbA1c Haemoglobin A1c
MAFLD Metabolic-Associated Fatty Liver Disease
NAFLD Non-Alcoholic Fatty Liver Disease
NASH Non-Alcoholic Steatohepatitis
NHLS National Health Laboratory Services
T2DM Type 2 Diabetes Mellitus

Conflict of Interest
The authors declare no conflict of interest.

Funding
This study was not funded by any external organization.

Data Availability
The data supporting the findings of this study are available upon reasonable request to the corresponding author.

Author Contributions
The author contributions section has been included, specifying the roles and contributions of each author. Londeka Ndaba (student) contributed to the study design, data collection, analysis, and manuscript writing. The supervisors, Ziningi Nobuhle Jaya and Nokukhanya Thembane, provided guidance in the study design, data interpretation, and manuscript revision. All authors have approved the final version of the manuscript.

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