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Original Research Article

Assessment of Subclinical Left Ventricular Dysfunction in Type 2 Diabetes Mellitus Using Echocardiographic Strain Imaging

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Abstract

Background : Type 2 diabetes mellitus (T2DM) is associated with a high burden of cardiovascular complications, including diabetic cardiomyopathy, which may develop before the onset of clinically apparent cardiac dysfunction. Conventional echocardiographic parameters such as left ventricular ejection fraction (LVEF) may fail to identify early myocardial abnormalities. Echocardiographic strain imaging, particularly global longitudinal strain (GLS), provides a sensitive method for detecting subclinical left ventricular (LV) dysfunction.

Aim : The present study was conducted to assess subclinical LV dysfunction in patients with T2DM using echocardiographic strain imaging and to evaluate its association with clinical and metabolic parameters.

Methods : This prospective observational study included 80 patients with type 2 diabetes mellitus who underwent clinical evaluation, biochemical assessment, conventional echocardiography, and two-dimensional speckle-tracking echocardiography (2D-STE). LV systolic function was assessed using LVEF, while myocardial deformation was evaluated using GLS. Associations between strain parameters and clinical variables, including duration of diabetes, glycaemic control, and cardiovascular risk factors, were analyzed.

Results : The mean age of study participants was 56.8 ± 9.4 years, with males comprising 62.5% of cases. The mean duration of diabetes was 8.2 ± 4.6 years. Although all patients had preserved LVEF (61.4 ± 4.8%), impaired GLS suggestive of subclinical LV dysfunction was observed in 40% of patients. Patients with impaired GLS had significantly longer duration of diabetes (10.8 ± 4.9 vs 6.5 ± 3.8 years, $p<0.001$) and higher HbA1c levels (8.5 ± 1.2 vs 7.3 ± 1.0%, $p<0.001$). GLS showed significant negative correlation with duration of diabetes and HbA1c levels.

Conclusion : Echocardiographic strain imaging enables detection of early myocardial dysfunction in patients with T2DM despite preserved LVEF. Global longitudinal strain may serve as a useful marker for early identification of diabetic cardiomyopathy and cardiovascular risk stratification.

Keywords : Type 2 diabetes mellitus; diabetic cardiomyopathy; global longitudinal strain; speckle-tracking echocardiography; subclinical left ventricular dysfunction; echocardiography.

Introduction

Type 2 diabetes mellitus (T2DM) is one of the most prevalent metabolic disorders worldwide and represents a major public health challenge due to its increasing incidence, chronic complications, and significant impact on cardiovascular morbidity and mortality. Cardiovascular disease remains the leading cause of death among individuals with diabetes.[1] In addition to traditional cardiovascular complications, diabetic cardiomyopathy has emerged as an important clinical entity characterized

by structural and functional myocardial abnormalities occurring independently of significant coronary artery disease, hypertension, or valvular disease. Diabetic cardiomyopathy is a complex pathological process involving multiple mechanisms, including chronic hyperglycaemia, oxidative stress, inflammation, endothelial dysfunction, myocardial fibrosis, mitochondrial impairment, and altered calcium handling.[2] Persistent hyperglycaemia promotes the accumulation of advanced glycation end-products and metabolic disturbances, resulting in myocardial remodeling and impaired cardiac performance. These changes often develop gradually and may remain clinically silent during the early stages. However, progressive myocardial injury can eventually lead to left ventricular (LV) dysfunction, heart failure with preserved ejection fraction (HFpEF), and symptomatic cardiac failure.[3] Early diabetic myocardial involvement is frequently characterized by impaired ventricular relaxation, increased myocardial stiffness, and subtle abnormalities in contractility, while conventional assessment of systolic function may remain normal. Left ventricular ejection fraction (LVEF), although widely used for evaluation of cardiac function, has limited ability to detect early myocardial dysfunction because significant reduction occurs only after considerable myocardial damage. [4,5] Therefore, diabetic patients with preserved LVEF may still have underlying abnormalities in myocardial mechanics that remain undetected by routine echocardiographic evaluation. Recent advances in cardiac imaging have introduced echocardiographic strain analysis as a sensitive method for identifying early myocardial dysfunction.[6] Two-dimensional speckle-tracking echocardiography (2D-STE) enables quantitative assessment of myocardial deformation by measuring changes in myocardial length during the cardiac cycle. Global longitudinal strain (GLS), which reflects the function of subendocardial longitudinal myocardial fibers, is considered one of the earliest markers of impaired LV systolic function.[7] Since these fibers are particularly susceptible to metabolic and microvascular injury in diabetes, reduction in GLS may occur before abnormalities in LVEF become apparent. Previous studies have demonstrated that patients with T2DM may exhibit impaired LV strain parameters despite the absence of overt cardiovascular disease. Factors such as longer duration of diabetes, poor glycaemic control, hypertension, obesity, insulin resistance, and diabetic microvascular complications have been associated with deterioration of myocardial deformation. [8,9] Among strain parameters, GLS has shown potential utility in detecting early diabetic myocardial involvement and predicting future cardiovascular risk. Thus, strain imaging may provide valuable information for early cardiovascular risk stratification and personalized management of diabetic patients.[10] Despite increasing evidence supporting the role of strain imaging, routine assessment of myocardial deformation is not yet widely incorporated into standard evaluation of individuals with T2DM. Variations in metabolic characteristics, patient profiles, and healthcare settings may influence the prevalence and severity of subclinical LV dysfunction. Furthermore, the relationship between myocardial strain abnormalities and clinical parameters, including age, sex, duration of diabetes, glycaemic status, and associated metabolic factors, requires further evaluation.[11]Early identification of subclinical LV dysfunction provides an opportunity for timely therapeutic interventions, including optimization of glycaemic control, lifestyle modification, and implementation of cardioprotective strategies before irreversible myocardial damage occurs.[12] Integration of strain imaging with conventional echocardiographic assessment may improve cardiovascular risk prediction and enable better management of patients with diabetes. Therefore, the present study was conducted to assess subclinical left ventricular dysfunction in patients with type 2 diabetes mellitus using echocardiographic strain imaging. The study aims to evaluate myocardial deformation parameters, particularly global longitudinal strain, and determine their association with clinical and metabolic characteristics. Early detection of diabetic myocardial abnormalities using advanced echocardiographic techniques may help identify high-risk individuals and prevent progression to overt cardiac dysfunction.

Methodology:

This prospective observational study was conducted to assess subclinical left ventricular dysfunction among patients with type 2 diabetes mellitus (T2DM) using echocardiographic strain imaging. The study was carried out in the Department of Medicine .A total of 80 patients diagnosed with type 2 diabetes mellitus were included in the study. Patients attending the outpatient department and those admitted to the hospital during the study period were screened for eligibility.

Inclusion Criteria

Patients were included if they fulfilled the following criteria:

- Adults aged ≥18 years.
- Diagnosed cases of type 2 diabetes mellitus according to standard diagnostic criteria.
- Patients willing to participate and provide written informed consent.
- Patients with preserved left ventricular ejection fraction (LVEF ≥50%) on

conventional echocardiographic evaluation.

Exclusion Criteria

Patients were excluded if they had:

- History of documented coronary artery disease, myocardial infarction, or previous coronary intervention.
- Known cardiomyopathy or established heart failure.
- Significant valvular heart disease.
- Persistent arrhythmias affecting echocardiographic assessment.
- Congenital heart disease.
- Chronic kidney disease requiring dialysis.
- Active systemic inflammatory or infectious disorders.
- Poor-quality echocardiographic images unsuitable for strain analysis.
- Patients unwilling to provide consent.

Clinical and Biochemical Assessment

Detailed clinical history was obtained from all participants, including age, sex, duration of diabetes, medication history, and presence of associated comorbidities such as hypertension and dyslipidaemia. Anthropometric measurements, including body weight, height, and body mass index (BMI), were recorded.Glycaemic status was assessed using fasting blood glucose, postprandial blood glucose, and glycated haemoglobin (HbA1c) levels. Additional biochemical investigations, including lipid profile and renal function tests, were performed as per standard clinical practice. Blood pressure measurements were recorded using standard methods.

Conventional Echocardiographic Assessment

All participants underwent transthoracic echocardiographic evaluation using a commercially available echocardiography system equipped with a phased-array transducer. Echocardiographic examinations were performed according to the recommendations of the American Society of Echocardiography.Conventional echocardiographic parameters including left ventricular dimensions, interventricular septal thickness, posterior wall thickness, left atrial size, transmitral flow velocities, and left ventricular ejection fraction (LVEF) were assessed. Left ventricular systolic function was evaluated using the biplane Simpson's method. Diastolic function parameters, including mitral inflow velocities (E and A waves), E/A ratio, and tissue Doppler-derived e′ velocity, were recorded.

Speckle-Tracking Echocardiography and Strain Analysis

Two-dimensional speckle-tracking echocardiography (2D-STE) was performed for assessment of myocardial deformation. Standard apical four-chamber, two-chamber, and three-chamber views were acquired with adequate frame rates for strain analysis.Global longitudinal strain (GLS) was calculated by automated or semi-automated tracking of myocardial motion throughout the cardiac cycle. The software generated strain curves for individual myocardial segments, and the average peak systolic longitudinal strain from all assessed segments was considered as the global longitudinal strain value.Subclinical left ventricular dysfunction was defined as impaired myocardial deformation despite preserved LVEF, particularly based on reduced GLS values. All strain measurements were performed by an experienced echocardiographer, and image quality was ensured before analysis.

Study Outcomes

The primary outcome of the study was to assess the presence of subclinical left ventricular dysfunction in patients with type 2 diabetes mellitus using echocardiographic strain imaging.

Secondary outcomes included:

- Evaluation of global longitudinal strain values among diabetic patients.
- Assessment of conventional echocardiographic parameters.
- Determination of the association between GLS and clinical variables such as age, sex, duration of diabetes, glycaemic control, and metabolic parameters.
- Assessment of factors associated with early myocardial dysfunction.

Statistical Analysis

Data were entered into a Microsoft Excel spreadsheet and analyzed using SPSS .21statistical software. Continuous variables were expressed as mean ± standard deviation or median with interquartile range, depending on data distribution. Categorical variables were presented as frequencies and percentages.The normality of continuous variables was assessed using the Shapiro–Wilk test. Comparisons between groups were performed using the independent Student's t-test or Mann–Whitney U test for continuous variables and the Chi-square test or Fisher's exact test for categorical variables.Correlation between GLS values and clinical or biochemical parameters was evaluated using Pearson's or Spearman's correlation analysis as appropriate. A p-value of <0.05 was considered statistically significant.

Results:

A total of 80 patients with type 2 diabetes mellitus (T2DM) were included in the present study. All participants underwent clinical evaluation, biochemical assessment, conventional

echocardiography, and two-dimensional speckle-tracking echocardiography (2D-STE) for assessment of subclinical left ventricular (LV) dysfunction. The mean age of the study population was 56.8 ± 9.4 years, with a predominance of male participants. The baseline demographic and clinical characteristics of the study participants are presented in Table 1.The majority of patients belonged to the age group of 51–60 years (37.5%), followed by 61–70 years (30.0%). Males constituted 62.5% of the study population, while females accounted for 37.5%. The mean duration of diabetes was 8.2 ± 4.6 years. Hypertension was the most common associated comorbidity, present in 55.0% of patients, followed by dyslipidaemia (41.3%) and obesity (32.5%) Table 1.

The mean fasting blood glucose level among study participants was 154.6 ± 38.2 mg/dL, while the mean HbA1c level was 7.8 ± 1.2%. Poor glycaemic control (HbA1c ≥7%) was observed in 61.3% of patients. The mean lipid profile parameters, including total cholesterol, LDL cholesterol, and triglycerides, are summarized in Table 2, Figure 1All patients had preserved left ventricular systolic function with a mean LVEF of 61.4 ± 4.8%. Conventional echocardiographic assessment showed evidence of diastolic dysfunction in a proportion of patients despite preserved systolic function. Grade I LV diastolic dysfunction was observed in 35.0% of patients, whereas normal diastolic function was observed in 65.0%. Other echocardiographic parameters including LV dimensions and Doppler indices are presented in Table 3.Speckle-tracking echocardiography revealed impaired myocardial deformation in a significant proportion of patients despite preserved LVEF. The mean global longitudinal strain (GLS) value was −17.8 ± 2.4%. Reduced GLS suggestive of subclinical LV dysfunction was observed in 32 patients (40.0%), while 48 patients (60.0%) demonstrated preserved strain values Table 4, Figure 2Patients with impaired GLS had significantly higher duration of diabetes, higher HbA1c levels, and greater prevalence of hypertension compared with patients with preserved GLS. The comparison of clinical and metabolic characteristics between patients with normal and impaired GLS is shown in Table 5, Figure 3

Correlation analysis demonstrated a significant negative correlation between GLS values and duration of diabetes ($r = -0.42$, $p<0.001$) and HbA1c levels ($r = -0.36$, $p=0.001$). Increasing duration of diabetes and poor glycaemic control were associated with worsening myocardial deformation. A significant association was also observed between GLS impairment and hypertension status (Table 6).

On univariate analysis, longer duration of diabetes, elevated HbA1c, hypertension, and dyslipidaemia were associated with reduced GLS values. Among these factors, duration of diabetes and poor glycaemic control remained significant predictors of subclinical LV dysfunction on multivariate analysis.

Table 1: Demographic and Clinical Characteristics of Study Participants (n=80)

Parameter	Number (%) / Mean ± SD
Age (years)	56.8 ± 9.4
Age group (years)	
≤50	18 (22.5%)
51–60	30 (37.5%)
61–70	24 (30.0%)
>70	8 (10.0%)
Male sex	50 (62.5%)
Female sex	30 (37.5%)
Duration of diabetes (years)	8.2 ± 4.6
Hypertension	44 (55.0%)
Dyslipidaemia	33 (41.3%)
Obesity	26 (32.5%)

Table 2: Glycaemic and Biochemical Parameters of Study Participants (n=80)

Parameter	Mean ± SD
Fasting blood glucose (mg/dL)	154.6 ± 38.2
Postprandial blood glucose (mg/dL)	232.4 ± 56.8
HbA1c (%)	7.8 ± 1.2
Total cholesterol (mg/dL)	192.6 ± 38.4
LDL cholesterol (mg/dL)	118.3 ± 32.6
HDL cholesterol (mg/dL)	42.8 ± 8.5
Triglycerides (mg/dL)	164.5 ± 52.7

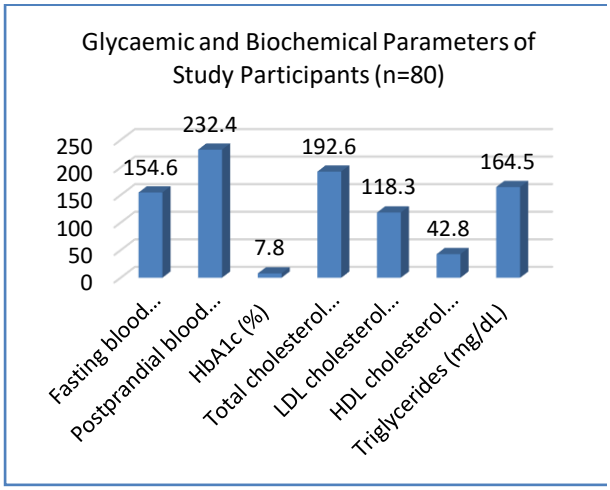


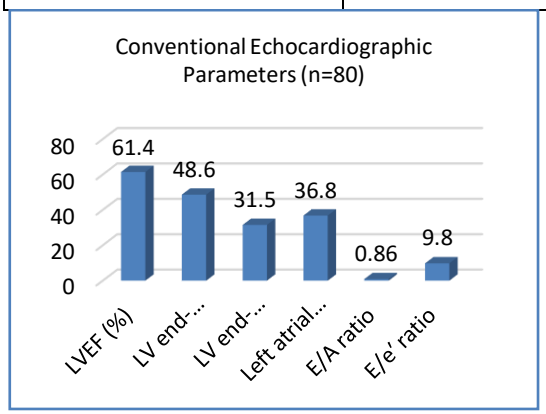
Figure 1 Glycaemic and Biochemical Parameters of Study Participants (n=80)

Table 3: Conventional Echocardiographic Parameters (n=80)

Parameter	Mean ± SD
LVEF (%)	61.4 ± 4.8
LV end-diastolic diameter (mm)	48.6 ± 4.2
LV end-systolic diameter (mm)	31.5 ± 3.6
Left atrial diameter (mm)	36.8 ± 4.1
E/A ratio	0.86 ± 0.21
E/e′ ratio	9.8 ± 2.7

Diastolic function status

Category	Number (%)
Normal	52 (65.0%)
Grade I diastolic dysfunction	28 (35.0%)



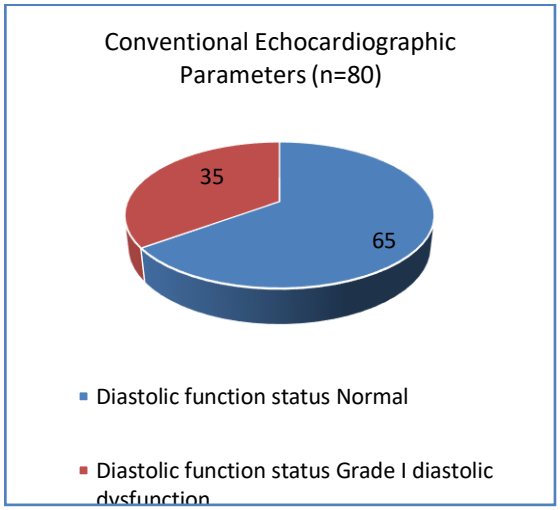


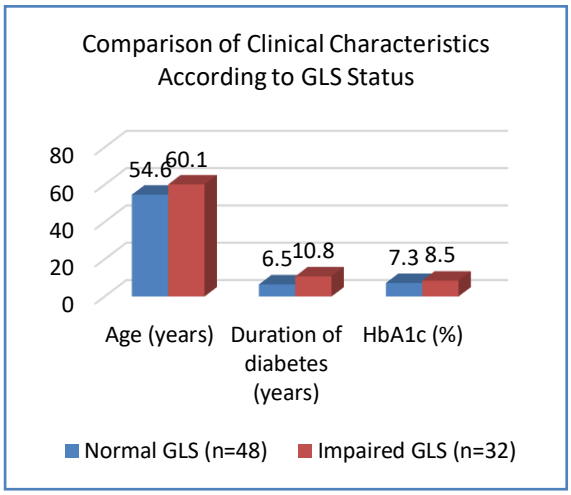
Figure 2 Conventional Echocardiographic Parameters (n=80)

Table 4: Distribution of Global Longitudinal Strain Findings (n=80)

GLS Category	Number (%)
Preserved GLS	48 (60.0%)
Impaired GLS (Subclinical LV dysfunction)	32 (40.0%)
Mean GLS (%)	−17.8 ± 2.4

Table 5: Comparison of Clinical Characteristics According to GLS Status

Parameter	Normal GLS (n=48)	Impaired GLS (n=32)	p-value
Age (years)	54.6 ± 8.9	60.1 ± 9.2	0.012
Duration of diabetes (years)	6.5 ± 3.8	10.8 ± 4.9	<0.001
HbA1c (%)	7.3 ± 1.0	8.5 ± 1.2	<0.001
Hypertension	20 (41.7%)	24 (75.0%)	0.004
Dyslipidaemia	16 (33.3%)	17 (53.1%)	0.047



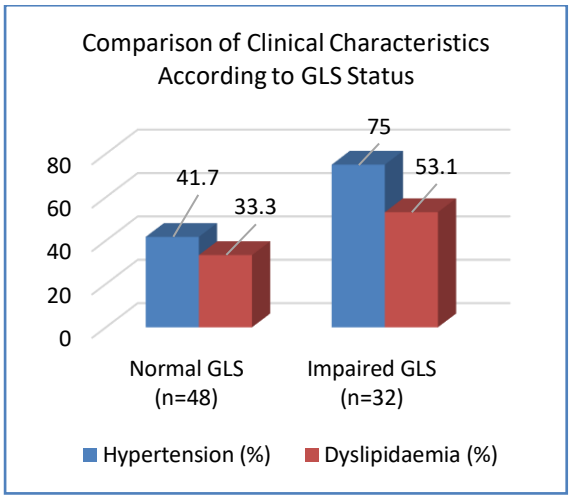


Figure 3 Comparison of Clinical Characteristics According to GLS Status

Table 6: Correlation Between GLS and Clinical/Biochemical Parameters

Parameter	Correlation coefficient (r)	p-value
Duration of diabetes	−0.42	<0.001
HbA1c	−0.36	0.001
Fasting glucose	−0.28	0.012
BMI	−0.24	0.031
Age	−0.30	0.007

Discussion

Type 2 diabetes mellitus (T2DM) is an important risk factor for cardiovascular disease and is associated with progressive myocardial structural and functional abnormalities. Diabetic cardiomyopathy may develop independently of coronary artery disease or hypertension and often remains clinically silent during the early stages. The present study evaluated subclinical left ventricular (LV) dysfunction among 80 patients with T2DM using conventional echocardiography and two-dimensional speckle-tracking echocardiography (2D-STE). The major finding was that a substantial proportion of diabetic patients exhibited early myocardial impairment despite preserved left ventricular ejection fraction (LVEF), emphasizing the role of strain imaging in detecting subtle cardiac abnormalities. In the present study, the mean age of participants was 56.8 ± 9.4 years, with male predominance (62.5%). The mean duration of diabetes was 8.2 ± 4.6 years, and hypertension was present in 55% of patients. Similar clinical characteristics have been reported by Nghiem et al. [13], who evaluated 232 patients with T2DM and preserved ejection fraction and demonstrated that diabetic patients frequently had associated cardiovascular risk factors. Their study reported LV diastolic dysfunction in 53.9% and impaired global longitudinal strain (GLS) in 13.4% of patients, supporting the presence of early myocardial involvement despite preserved systolic function. In the current study, conventional echocardiography showed preserved LV systolic function, with a mean LVEF of 61.4 ± 4.8%. However, strain imaging identified abnormalities in myocardial deformation, demonstrating the limitations of LVEF for detecting early diabetic myocardial dysfunction. Similar findings were reported by who showed that patients with T2DM and preserved LVEF may have impaired longitudinal myocardial function, suggesting that GLS can detect early myocardial involvement before conventional systolic dysfunction becomes apparent. The present study observed a mean GLS value of −17.8 ± 2.4%, with impaired GLS suggestive of subclinical LV dysfunction in 40% of patients. These findings indicate that myocardial deformation abnormalities may occur frequently in diabetic individuals without overt cardiovascular disease. Ng et al. [14] evaluated 397 patients with T2DM and demonstrated that LV GLS was effective in identifying subclinical systolic dysfunction and provided additional prognostic information beyond conventional cardiovascular assessment. Their findings support the clinical utility of GLS for early cardiovascular risk stratification in diabetic patients. The proportion of impaired GLS observed in our study was higher than that reported in some previous studies, which may be explained by differences in patient characteristics, duration of diabetes, glycaemic status, and associated comorbidities. In the present study, patients with impaired GLS had significantly longer duration of diabetes (10.8 ± 4.9 vs 6.5 ± 3.8 years; p<0.001) and higher HbA1c levels (8.5 ± 1.2

vs 7.3 ± 1.0%; p<0.001) compared with those with preserved GLS. These findings highlight the contribution of prolonged hyperglycaemia and cumulative metabolic stress in the development of myocardial dysfunction. The association between poor glycaemic control and reduced myocardial strain is consistent with previous evidence. Gao et al. [15] reported that HbA1c levels were independently associated with impaired GLS among patients with T2DM and preserved LVEF, indicating that inadequate metabolic control contributes to early myocardial injury. In the present study, GLS showed a significant negative correlation with duration of diabetes (r = −0.42, p<0.001) and HbA1c (r = −0.36, p=0.001), suggesting progressive deterioration of myocardial deformation with increasing disease duration and worsening glycaemic control. Chronic hyperglycaemia may contribute to this process through oxidative stress, advanced glycation end-product accumulation, myocardial fibrosis, and impaired myocardial energy metabolism. Hypertension was another significant factor associated with impaired GLS in the present study. Patients with reduced GLS had a higher prevalence of hypertension compared with those with preserved strain (75% vs 41.7%; p=0.004). The coexistence of diabetes and hypertension may accelerate myocardial remodeling through increased ventricular afterload, fibrosis, and impaired relaxation, further contributing to diabetic cardiomyopathy. The clinical importance of GLS assessment lies in its ability to detect myocardial dysfunction before the development of overt cardiac failure. Wu et al. [16] demonstrated that diabetic patients with preserved LVEF exhibited reduced strain parameters, supporting the role of speckle-tracking echocardiography as a sensitive technique for early identification of myocardial abnormalities. A systematic review has also highlighted the usefulness of strain imaging in detecting subclinical cardiac dysfunction among diabetic patients. The findings of the present study have important clinical implications. Detection of impaired GLS in asymptomatic diabetic patients may facilitate early cardiovascular risk assessment and allow timely interventions, including improved glycaemic control, lifestyle modification, management of hypertension and dyslipidaemia, and initiation of cardioprotective therapies when appropriate. In conclusion, the present study demonstrated that a significant proportion of patients with T2DM had subclinical LV dysfunction despite preserved LVEF. Reduced GLS was associated with longer duration of diabetes, poor glycaemic control, and hypertension. These findings support the incorporation of echocardiographic strain imaging into routine cardiovascular evaluation of diabetic patients for early detection of diabetic cardiomyopathy and prevention of progression to heart failure.

Conclusion

The present study demonstrated that a significant proportion of patients with type 2 diabetes mellitus exhibited subclinical left ventricular dysfunction despite preserved ejection fraction on conventional echocardiography. Echocardiographic strain imaging, particularly global longitudinal strain, provided sensitive detection of early myocardial impairment. Reduced GLS was associated with longer duration of diabetes, poor glycaemic control, and associated cardiovascular risk factors. Strain-based assessment may therefore serve as a valuable tool for early identification of diabetic cardiomyopathy and implementation of preventive cardiovascular strategies.

Limitations

The present study was limited by its relatively small sample size of 80 patients and single-centre study design, which may affect the generalizability of the findings. The cross-sectional nature of the study prevented assessment of long-term progression of strain abnormalities and cardiovascular outcomes. Further multicentre studies with larger populations and longitudinal follow-up are required to validate the prognostic significance of strain imaging in diabetic cardiomyopathy.

References

1. Hoek AG, Dal Canto E, Wenker E, Bindraban N, Handoko ML, Elders PJM, et al. Epidemiology of heart failure in diabetes: A disease in disguise. Diabetologia. 2024;67:574-601.
2. Pop-Busui R, Januzzi JL, Bruemmer D, Butalia S, Green JB, Horton WB, et al. Heart Failure: An Underappreciated Complication of Diabetes. A Consensus Report of the American Diabetes Association. Diabetes Care. 2022;45:1670-1690.
3. Akasheva DU, Utina TG, Dzhioeva ON, Drapkina OM. Subclinical left ventricular dysfunction over seven-year follow-up in type 2 diabetes patients without cardiovascular diseases. Biomedicines. 2024;12:2031.
4. Borlaug BA, Paulus WJ. Heart failure with preserved ejection fraction: Pathophysiology, diagnosis, and treatment. Eur Heart J. 2011;32:670-679.
5. Kannel WB, Hjortland M, Castelli WP. Role of diabetes in congestive heart failure: The Framingham study. Am J Cardiol. 1974;34:29-34.

6. Abudureyimu M, Luo X, Wang X, Sowers JR, Wang W, Ge J, et al. Heart failure with preserved ejection fraction (HFpEF) in type 2 diabetes mellitus: From pathophysiology to therapeutics. J Mol Cell Biol. 2022;14:mjac028.
7. Jia G, Whaley-Connell A, Sowers JR. Diabetic cardiomyopathy: A hyperglycaemia- and insulin-resistance-induced heart disease. Diabetologia. 2018;61:21-28.
8. Muñoz-Córdova F, Hernández-Fuentes C, Lopez-Crisosto C, Troncoso MF, Calle X, Guerrero-Moncayo A, et al. Novel insights into the pathogenesis of diabetic cardiomyopathy and pharmacological strategies. Front Cardiovasc Med. 2021;8:707336.
9. Tanaka H. Utility of strain imaging in conjunction with heart failure stage classification for heart failure patient management. J Echocardiogr. 2019;17:17-24.
10. Sengeløv M, Jørgensen PG, Jensen JS, Bruun NE, Olsen FJ, Fritz-Hansen T, et al. Global longitudinal strain is a superior predictor of all-cause mortality in heart failure with reduced ejection fraction. JACC Cardiovasc Imaging. 2015;8:1351-1359.
11. Chimura M, Onishi T, Tsukishiro Y, Sawada T, Kiuchi K, Shimane A, et al. Longitudinal strain combined with delayed-enhancement magnetic resonance improves risk stratification in patients with dilated cardiomyopathy. Heart. 2017;103:679-686.
12. Lang RM, Badano LP, Mor-Avi V, Afilalo J, Armstrong A, Ernande L, et al. Recommendations for cardiac chamber quantification by echocardiography in adults: An update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. J Am Soc Echocardiogr. 2015;16:233-271.
13. Nghiem TP, Tran HM, Nguyen DNQ, Dao LT, Tran CC, Vo TM, et al. Subclinical myocardial dysfunction in type 2 diabetes mellitus: insights from left ventricular diastolic function and global longitudinal strain assessment. Med Sci (Basel). 2025;13(4):237.
14. Ng ACT, Delgado V, Bertini M, van der Meer RW, Rijzewijk LJ, Hooi Ewe SH, et al. Defining subclinical myocardial dysfunction and implications for patients with diabetes mellitus and preserved ejection fraction. J Am Coll Cardiol. 2019;74:1254-1266.
15. Gao J, Xu M, Gong M, Jiang S, Yang Z, Jiang X, et al. Left ventricular longitudinal strain in patients with type 2 diabetes mellitus is independently associated with glycated hemoglobin level. Clin Cardiol. 2023;46:1578-1587.
16. Wu T, Li X, Zhang D, Gong LG. Early impairment of right ventricular systolic function in patients with prediabetes and type 2 diabetes mellitus: an analysis of two-dimensional speckle tracking echocardiography. Echocardiography. 2023;40:831-840

Patel ND, Nikhil MD, Marathi BC, Danish M, Sonnad N. Assessment of subclinical left ventricular dysfunction in type 2 diabetes mellitus using echocardiographic strain imaging. Ann Adv Med Sci. 2026;1(2):186-193.