Original Article

Association of muscle performance and heart rate variability in middle-aged type 2 diabetes mellitus

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Abstract

Background: Type 2 diabetes mellitus (T2DM) is characterized by insulin resistance, which impairs the metabolism of carbohydrates, lipids, and proteins. Recent findings indicate that skeletal muscle atrophy, decreased muscle strength, and reduced muscle performance have become prevalent complications of diabetes. Additionally, dysfunction of cardiac autonomic nerves also leads to skeletal muscle impairment. These issues further exacerbate diabetes, thereby leading to a vicious cycle. This study investigates the association between muscle performance and cardiac autonomic neuropathy in middle-aged T2DM patients. **Material and Methods:** In this case–control study, we included 51 diagnosed T2DM patients aged 30-55 years, with a duration of T2DM less than 5 years and HbA1C level below 8%. We also included 51 age-, sex-, and BMI-matched healthy control subjects. Muscle performance was assessed by evaluating the core endurance through the trunk flexor endurance test (TFET), trunk lateral endurance test (TLET), trunk extensor endurance test (TEET), along with hamstring muscle flexibility through the active knee extension (AKE) test. Cardiac autonomic function was evaluated using the heart rate variability test. Statistical analyses were performed using GraphPad Prism version 9. The Mann–Whitney test was used to compare the two groups, and data were represented as median (interquartile range). Values were considered statistically significant at P value ≤ 0.05. **Results:** We observed a significant decrease in core endurance (TFET, TLET, TEET) with P values < 0.001, as well as reduced hamstring muscle flexibility shown by a decrease in the degree of AKE test with P value < 0.001 in the T2DM patients when compared with the controls. Furthermore, heart rate variability in both time domain parameters (SDRR, CVRR, SDSD, RMSSD, pRR50%) and frequency domain parameters (Total power, VLF, LF, HF, LF/HF) also showed significant decreases, with P values < 0.001 in the T2DM group compared to the control group. **Conclusion:** The observed decrease in muscle performance and heart rate variability parameters in middle-aged newly diagnosed T2DM patients suggests early skeletal muscle atrophy and cardiac autonomic dysfunction.

Keywords: Cardiac autonomic neuropathy, core endurance, heart rate variability, muscle flexibility, muscle performance, sarcopenia, type 2 diabetes mellitus

Introduction

Type 2 diabetes mellitus (T2DM) is a prevalent metabolic disorder characterized by alterations in carbohydrate metabolism resulting from decreased insulin sensitivity in target tissues, accompanied by a relative deficiency in insulin secretion. T2DM is characterized by abnormalities in protein and lipid metabolism.[1]

This protein and lipid metabolism disorder leads to skeletal muscle atrophy in diabetes. Apart from the chronic micro- and macrovascular complications of T2DM, damage to the skeletal muscles with a progressive decline in muscle quality has been described as a new complication in diabetes. This recently

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Received: 04-11-2024 **Revised:** 11-01-2025
Accepted: 18-01-2025 **Published:** 25-04-2025

Access this article online
Quick Response Code:
Website: http://journals.lww.com/JFMPC
DOI: 10.4103/jfmpc.jfmpc_1803_24

How to cite this article: Ansari MA, Zaidi AS, Akhter P, Gautam S, Kohli S, Alam I. Association of muscle performance and heart rate variability in middle-aged type 2 diabetes mellitus. J Family Med Prim Care 2025;14:1502-12.

identified comorbidity, reviewed in many current studies, is termed as *sarcopenia*.[2] The prevalence of skeletal muscle atrophy (SMA), an extreme form of sarcopenia, is notably higher in patients with diabetes. An early study by Park *et al*.[3] found that muscle mass decline was twofold faster in people with T2DM than in those without. Progressive skeletal muscle atrophy leads to decreased performance and poor quality of life for diabetic patients.

Flexibility and core endurance are simple methods of measuring muscle performance. A decrease in muscle performance promotes a sedentary lifestyle and further aggravates diabetes, forming a vicious cycle that can lead to various chronic complications of T2DM, such as peripheral neuropathy, foot ulcers, amputations, cardiovascular morbidity, and mortality.[4] In T2DM, decreased muscle quality, power, and strength are not only due to changes in nerve function caused by T2DM, but also because premature muscle fatigue can influence these factors.[5,6]

One of the common microvascular complications of T2DM is sudden cardiac arrest, and it is observed that heart failure is typically accompanied by skeletal muscle abnormalities that contribute to exercise intolerance and poor health-related quality of life, usually seen in these patients.[7,8] The autonomic nervous system (ANS) regulates the heart rate (HR) through sympathetic and parasympathetic branches. The autonomic nervous system (ANS) plays an important role in maintaining cellular homeostasis. In general, the sympathetic nervous system modulates several functions of skeletal muscle cells, such as acetylcholine release from the motor endplate, ionic fluxes through the membrane, glucose, and protein metabolism, calcium (Ca^{2+}) release, and re-uptake from the sarcoplasmic reticulum. These actions have implications for several features of muscle contraction such as the velocity of contraction and relaxation, force amplitude, and impairments that can contribute to fatigue.[9]

It has been correctly postulated that the composite impact of these (poor muscle performance and cardiac autonomic neuropathy) mutually aggravating maladies heightens the chance of morbidity and mortality. The decrease in muscle performance in the middle-aged group in T2DM has not been extensively studied in the Indian population. The findings of the few studies that have been done on the subject appear to be inconsistent in their conclusions. The increasing prevalence of diabetic sarcopenia presents a dire need for proper assessment of muscle performance in diabetic patients.[10] To explore this field of interest, the present study was designed to investigate the association of heart rate variability, core endurance, and muscle flexibility in type 2 diabetes mellitus for this seldom examined age bracket.

Material and Methods

This case–control study was conducted in a tertiary care hospital after obtaining ethical clearance from the Institutional Ethical Committee. Before the study, written informed consent was obtained from all the participants explaining the objectives of the study.

Cases were recruited through convenience sampling from the medicine OPD. Cases included patients with diagnosed type 2 diabetes mellitus on oral hypoglycemic drugs, meeting inclusion and exclusion criteria. Also, a control group of age-, sex-, and BMI-matched healthy subjects was recruited from the general population after obtaining informed consent from the volunteers. Inclusion criteria of the cases are subjects diagnosed with type 2 diabetes mellitus, male and female, aged 30–55 years, HbA1c <8%, duration of diabetes less than 5 years, and with a body mass index (BMI) of 18.5 to 29.9 kg/m² recruited for the study. Diabetes was diagnosed based on the revised American Diabetic Association Criteria, that is, fasting plasma glucose ≥126 mg/dl (≥6.1 mmol/1) and 2 h postprandial plasma glucose ≥200 mg/dl (≥1 1.1 mmol/l). Subjects with BMI ≥30 kg/m², age ≥55 years, myopathy, hypertension, peripheral neuropathy, abdominal surgery, pregnancy, and a history of chronic cigarette smoking. (regular smoker) (CDC), or regular alcohol intake greater than 28 units per week (male) or 21 units/week (female) were excluded from the study.

At the onset of the study, a proforma was filled with information about individual subjects regarding their general health status, history of illness, and medical family history and habits.

Sample size

The sample size was calculated using G*power.

Group A: Control group (n = 51)

Group B: Cases (T2DM patients) (n = 51)

The following parameters were evaluated in both the groups.

Core muscle endurance

McGill's test was used to examine participants core endurance.[11] The equipment required for the test included a stopwatch, board (or step), strap, elevated, sturdy examination table, and mat. McGill's core endurance tests included the trunk flexor endurance test (TFET), trunk lateral endurance test (TLET), and trunk extensor endurance test (TEET).

a. Trunk Flexor Endurance Test (TFET)

The flexor endurance test assesses the endurance of the deep core muscles (transverse abdominis, quadratus lumborum, and erector spinae).

Test procedure: Image 1(a), Image 1(b).

The purpose of the flexor endurance test was explained, and proper body position was described. The starting position required the subject to be seated with the hips and knees bent to 90°, aligning the hips, knees, and second toe. The subjects were instructed to fold their arms across the chest, touch each hand to the opposite shoulder, lean against a board positioned at a 60-degree incline, and maintain their head in a neutral position. The subject was asked to press the shoulders on the board and maintain this "open" position throughout the test after the board was removed. The patient was instructed to engage the abdominals to maintain a flat to neutral spine. The back was not allowed to arch during testing. The goal of the test is to hold this 60-degree position for as long as possible without the benefit of back support. Encourage the client to practice this position before testing. The examiner should start the stopwatch as he or she moves the board about 4 inches (10 cm) back, while the client maintains a 50- to 60-degree suspended position. Terminate the test when there is a noticeable change in the trunk position: Watch for a deviation from the neutral spine (i.e., shoulders rounding forward) or an increase in the low-back arch. None of the back touched the backrest. The patient's time on the recording sheet was recorded.

b. Trunk Lateral Endurance Test (TLET)

The trunk lateral endurance test, also called the side-bridge test, assesses the endurance of the lateral core muscles (transverse abdominis, oblique, quadratus lumborum, and erector spinae). Test procedure: Image 2

The purpose of this test is explained, and proper body position is described. The starting position required the subject to be on their side with extended legs, aligning their feet on top of each other, or in a tandem position (heel-to-toe). The subject placed the lower arm under the body and the upper arm on the side of the body. When the subject was ready, they were instructed to assume a full side-bridge position, keeping both legs extended and feet on the floor. The elbow of the lower arm should be positioned directly under the shoulder with the forearm facing out (the forearm can be placed palm-down for balance and support), and the upper arm should rest along the side of the body or across the chest to the opposite shoulder. The hips should be elevated off the mat, and the body should be aligned straight (i.e., head, neck, torso, hips, and legs). The torso should be supported only by the subject's feet, elbows, or forearm of the lower arm. The goal of the test is to maintain this position for as long as possible. Once the subject broke their position, the test was terminated. The subject was encouraged to practice this position before testing. The examiner started the stopwatch as the subject moved to the side bridge position. Terminate the test when there is a noticeable change in the trunk position. The subjects' times were recorded on a recording sheet. The test was repeated on the opposite side, and this value was recorded on the recorded sheet.

c. Trunk Extensor Endurance Test (TEET)

The trunk extensor endurance test is generally used to assess the endurance of torso extensor muscles (i.e., erector spinae, longissimus, iliocostalis, and multifidi).

Test procedure: Image 3

Explain the purpose of the test and explain the proper body positions. The starting position required the subject to be prone,

Image 1: (a) Trunk flexor endurance test

Image 1: (b) Trunk flexor endurance test

Image 2: Trunk lateral endurance test

Image 3: Trunk extensor endurance test

with the iliac crests positioned at the table edge while supporting the upper extremity on the arms, which were placed on the floor or riser. While the subject supported the weight of his or her upper body, anchor the subject's lower legs to the table using a strap, or somebody can hold. The goal of the test was to hold the subject in a horizontally prone position for as long as possible. Once the participant fell below the horizontal position, the test was terminated. Encourage the client to practice this position before testing. When ready, the subject lifts/extends the torso until it is parallel to the floor with his or her arms crossed over the chest. The stopwatch was started as soon as the client assumed this position. The test was terminated when the client could no longer maintain their position. The subjects' times were recorded on a recording sheet.

Hamstring muscle flexibility by active knee extension (AKE) Test

Test Procedure: Image 4

The AKE test was performed with the participants lying supine on the examination couch. The hip and knee were flexed to 90° and held in position using a wooden box, while the non-tested lower extremity was firmly attached to the couch with the help of a Velcro strap tied across the mid-thigh and maintaining the foot in a relaxed position while maintaining the posterior aspect of the thigh in contact with the box. The subjects are asked to extend their knees until they start to feel a stretch sensation in the posterior thigh. Using a universal goniometer, the angle of knee extension was measured by the angle between a line adjoining the greater trochanter and femoral condyle, while the other line joined the head of the fibula and lateral malleolus.

Heart rate variability test

AD instruments laboratory Chart pro version 8.1.13 was used as data acquisition software for recording heart rate variability.

Test Procedure:

All participants are required to refrain from consuming caffeine, alcohol, and tobacco products for at least 12 hours before the test. Subjects are asked to lie down and relax for 5 minutes before the start of the recording. They are also instructed to close their eyes and avoid any movements or conversation during the recording. Lead II electrocardiographic (ECG) recording was done for 5 minutes in the supine position. After recording, all data were stored and analyzed offline. The time and frequency domain parameters of HRV were analyzed by detecting the R waves.

Statistical analysis

Statistical analyses were performed using GraphPad Prism version 9. Normality was calculated using the D'Agostino and Pearson test, and data were not normal; hence, the Mann–Whitney test was used to compare the two groups, and data are represented as median (interquartile range). Correlations were assessed using Spearman's correlation test. Values were considered statistically significant at P value < 0.05.

Observation and Result

In this study, 51 diagnosed type 2 diabetes mellitus cases meeting the inclusion and exclusion criteria and providing valid written consent were included in the study. A group of 51 normal individuals without diabetes served as controls in this study. The observations made in this study are as follows.

The baseline characteristics of 51 diagnosed T2DM cases show mean age in years of 43.72 ± 7.11, duration of diabetes in years of 4.64 ± 1.83, random blood glucose levels in mg/dl of 183.31 ± 51.11, mean HbA1c levels 7.85 ± 1.75% along with age-, sex-, and BMI-matched controls as shown in Table 1. There was no significant difference in age, sex, BMI, and diastolic blood pressure between cases and controls. However, random blood glucose levels, HbA1C levels, and systolic blood pressure were significantly increased in cases compared to the control group.

Table 1: Baseline characteristics. Data are expressed as Mean ± S. D for 51 controls and 51 cases (T2DM patients). *P value ≤ 0.05 is significant.

HRV test was performed to assess the cardiac autonomic neuropathy. The results were compiled and analyzed as follows:

As shown in Table 2, heart rate variability test time-domain parameters (SDRR, CVRR, SD rate, SDSD, RMSSD, and pRR50)

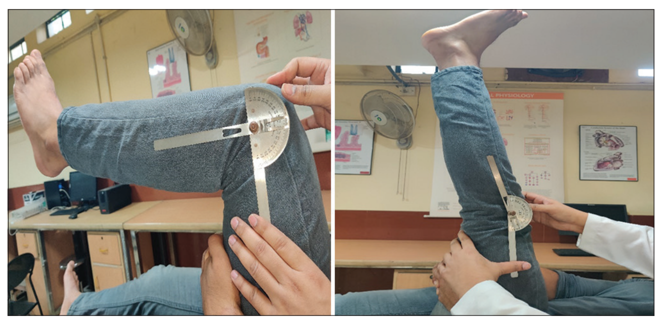

Image 4: Active knee extension test

Table 1: Baseline characteristics of non-diabetic control group (n=51) and T2DM Cases group (n=51)

	Controls (mean±S.D) (n=51)	Cases (mean±S.D) (n=51)	P
Male/female	47/4	47/4	
Age (yrs)	34.62±4.66	43.72±7.11	0.168
Duration of T2DM (years)	0	4.64±1.83	
Weight (kg)	67.03±5.61	68.25±8.76	0.196
Height (m)	171.61±6.23	166.44±6.43	0.143
BMI (Kg/m^2)	22.74±1.38	24.63±2.46	0.164
Systolic BP (mmHg)	119.29±5.45	135.60±8.80	0.054*
Diastolic BP (mmHg)	78.03±5.51	78.66±9.70	0.189
Random blood sugar (mg/dl)	113.39±7.58	183.31±51.11	0.001*
HbA1C (%)	5.13±1.24	7.85±1.75	0.001*

showed a significant decrease in the cases (T2DM patients) as compared to the controls.

Table 2: Values of time domain parameters of heart rate variability test. Data are expressed as median (interquartile range) for 51 T2DM patients and 51 controls. **P* value < 0.05 is significant.

Heart rate variability test frequency domain parameters (total power, VLF, LF, HF, and LF/HF) were markedly decreased in the cases T2DM patients when compared with the controls as shown in Table 3.

Table 3: Values of frequency domain parameters of heart rate variability test. Data are expressed as median (interquartile range) for 51 T2DM patients and 51 controls. * *P* value < 0.05 is significant.

In the cases (T2DM patient), no significant correlation was observed between frequency domain parameters (LF, HF, LF/HF) of HRV and HbA1c level as shown in Figure 1a – Figure 1c.

To assess muscle flexibility, an active knee extension test (AKE) was performed on both lower limbs. There was a significant decrease in active knee extension in both the lower limbs in cases as compared to controls [Table 4].

Table 4: Values of hamstring muscle flexibility parameters. Data are expressed as median (interquartile range) for 51 T2DM patients and 51 controls. **P* value < 0.05 is significant.

In T2DM patients, no significant correlation was present between HbA1c levels and AKE test in both the lower limbs [Figure 2a and Figure 2b].

To assess deep core muscle endurance, trunk flexor endurance test (TFET), trunk lateral endurance test (TLET), and trunk extensor endurance test (TEET) were performed. A significant decrease was observed in all the core muscle endurance parameters (TFET, TLET, and TEET) in the cases T2DM group as compared to the controls [Table 5].

Table 5: Values of core muscle endurance parameters. Data are expressed as median (interquartile range) for 51 T2DM patients and 51 controls. **P* value < 0.05 is significant.

The correlation between HbA1C and core endurance parameters (TFET and TLET) in T2DM patients was not significant [Figure 3a-3c], whereas a significant positive correlation was observed between the trunk extensor endurance test and HbA1c levels in T2DM patients [Figure 3d].

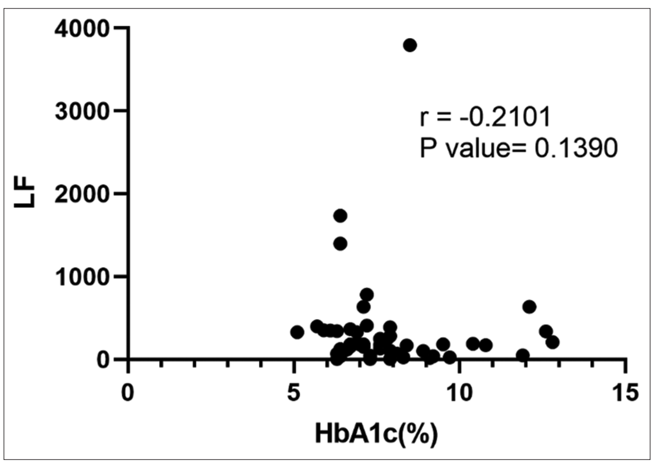

Figure 1a: The graph represents the correlation between HbA1c levels with LF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is -0.2010, and p value is 0.1390

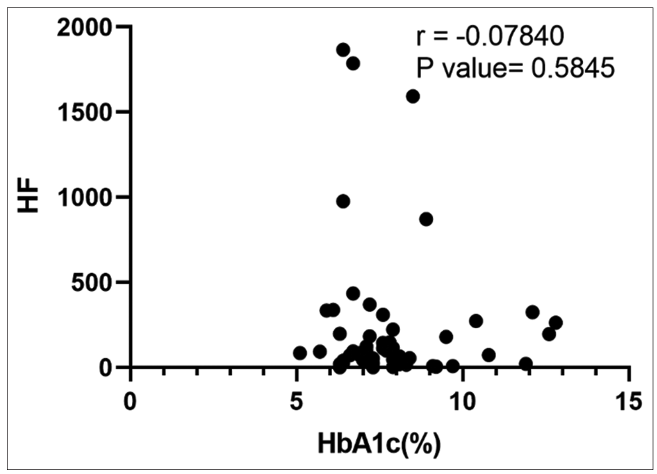

Figure 1b: The graph represents the correlation between HbA1c levels with HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is -0.07840, and p value is 0.5845

Table 2: Heart rate variability test time domain parameters in non-diabetic control and cases (T2DM patients)

Parameters	Controls Median (interquartile range) (*n*=51)	Cases Median (interquartile range) (*n*=51)	*P*
Avg RR (ms)	787.8 (712.5,1010)	765.9 (660.6,810.2)	0.1512
Median RR (ms)	788.0 (703.0,1018)	767.0 (656.0,812.5)	0.1876
SDRR (ms)	54.80 (32.24,69.26)	28.01 (18.65,34.44)	<0.0001*
CVRR	0.05999 (0.04758,0.07461)	0.03521 (0.02526,0.04546)	<0.0001*
Avg Rate (BPM)	76.36 (59.67,84.96)	78.59 (74.09,90.99)	0.2087
SD Rate (BPM)	4.492 (3.527,5.671)	2.633 (2.633,3.786)	<0.0001*
SDSD (ms)	53.90 (27.17,75.41)	14.72 (10.41,23.9)	<0.0001*
RMSSD (ms)	52.14 (27.14,68.65)	14.70 (10.40,23.96)	<0.0001*
pRR50 (%)	33.66 (7.950,50.16)	0.7916 (0.000,2.795)	<0.0001*

The correlation between muscle flexibility parameter (AKET) of both lower limbs and the respective frequency-domain HRV parameters (LF, HF, and LF/HF) was not significant [Figure 4a- Figure 4c].

The correlation between core muscle endurance test parameters (TFET, TLET, TEET) and the respective frequency domain HRV parameters (LF, HF, and LF/HF) was not significant [Figure 5a – Figure 5i].

Discussion

To the best of our knowledge, this study is one of its kind, assessing the association of muscle performance and heart rate variability in middle-aged type 2 diabetes mellitus (T2DM). Most of the existing studies have been directed at assessing the muscle performance either in the elderly diabetic or diabetic peripheral neuropathy group.[12,13] Middle-aged group with recently diagnosed diabetes is targeted in this study to take timely mitigation measures against the physiological decrease in muscle performance because of aging and preempt the degenerative complication lest it attains harmful proportions [Table 1].

Table 3: Heart rate variability test frequency domain parameters in non-diabetic controls and cases (T2DM patients)

Parameters	Controls Median (interquartile range) (n=51)	Cases Median (interquartile range) (n=51)	*P*
Total (ms^2)	2807 (969.2,4122)	736.5 (228.7,1374)	<0.0001*
VLF (ms^2)	682.6 (333.4,1550)	406.2 (106.3,778.9)	0.0002*
LF (ms^2)	687.0 (311.4,1220)	181.9 (67.99,341.1)	<0.0001*
HF (ms^2)	1126 (282.4,1696)	94.39 (39.89,262.3)	<0.0001*
LF/HF	0.7927 (0.4746, 1.382)	1.856 (1.256, 3.114)	<0.0001*

Table 4: Hamstring muscle flexibility parameters in non-diabetic controls and cases (T2DM patients)

Parameters	Controls Median (interquartile range) (n=51)	Cases Median (interquartile range) (n=51)	*P*
AKE TEST (RT) (degree)	10.00 (9.000,12.00)	26.00 (18.00,33.00)	<0.0001*
AKE TEST (LT) (degree)	10.00 (9.000,13.00)	26.00 (20.00,32.00)	<0.0001*

AKE test: Active Knee Extension test; RT-right, LT-left

Table 5: Core muscles endurance parameters in non-diabetic controls and cases (T2DM patients)

Parameters	Controls Median (interquartile range) (n=51)	Cases Median (interquartile range) (n=51)	*P*
TFET (sec)	121.0 (108.0,132.0)	44.00 (32.00,60.00)	<0.0001*
TLET (RT) (sec)	79.00 (73.00,82.00)	38.00 (29.00,48.00)	<0.0001*
TLET (LT) (sec)	76.00 (72.00,80.00)	36.00 (29.00,41.00)	<0.0001*
TEET (sec)	98.00 (89.00,102.0)	50.00 (38.00,56.00)	<0.0001*

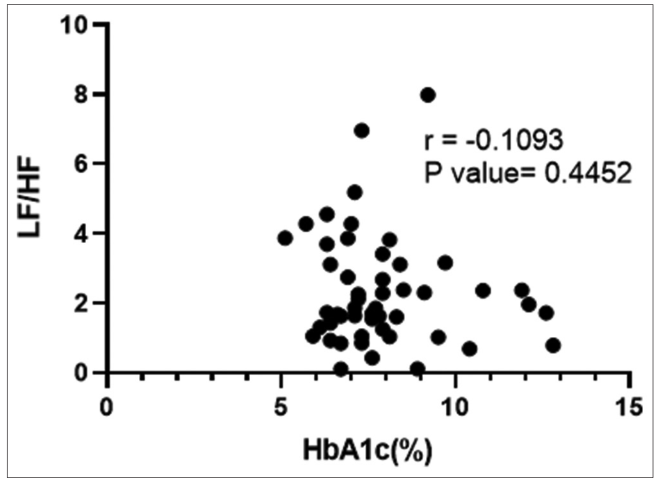

Figure 1c: The graph represents the correlation between HbA1c levels with LF/HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is -0.1093, and p value is 0.4452

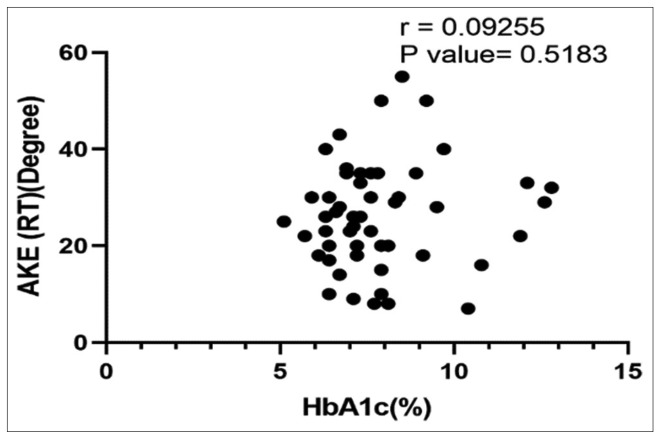

Figure 2a: The graph represents the correlation between HbA1c levels with AKE test (RT) in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.09255, and p value is 0.5183

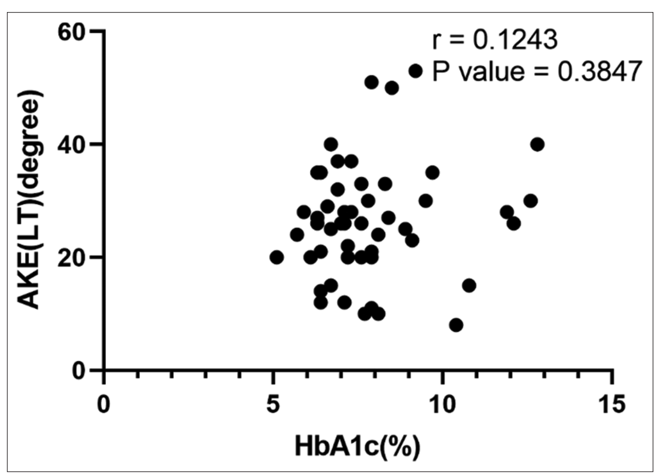

Figure 2b: The graph represents the correlation between HbA1c levels with AKE test (LT) in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.1243, and p value is 0.3847

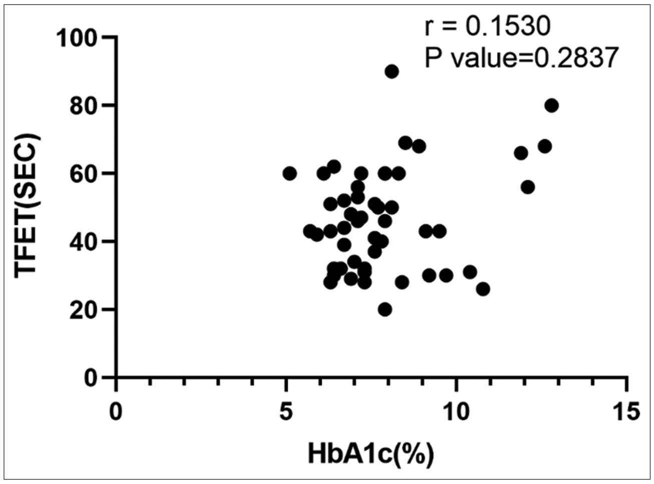

Figure 3a: The graph represents the correlation between HbA1c levels with TFET in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.1530, and p value is 0.2837

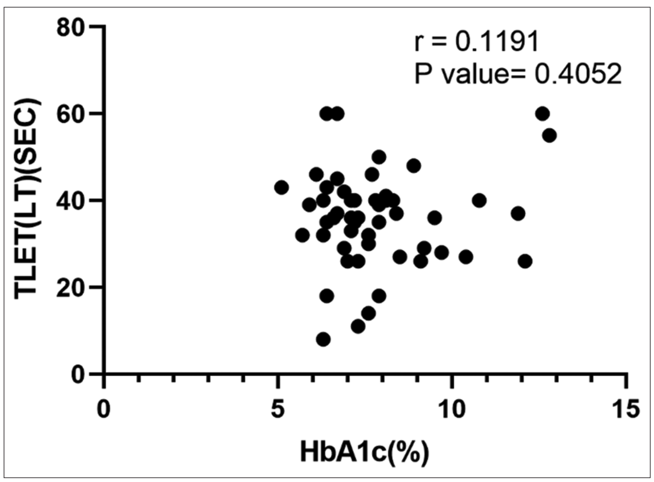

Figure 3c: The graph represents the correlation between HbA1c levels with TLET (LT) in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.1191, and p value is 0.4052

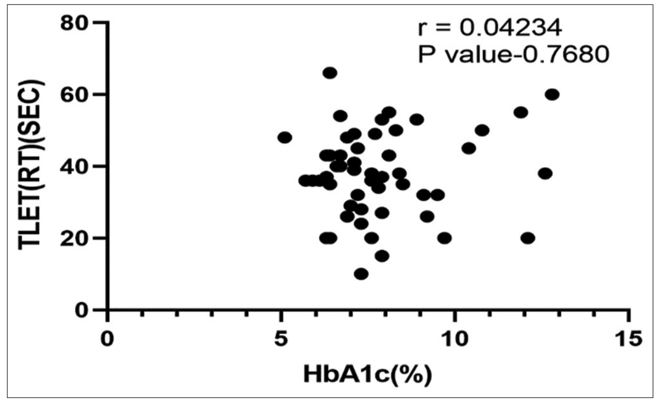

Figure 3b: The graph represents the correlation between HbA1c levels with TLET (RT) in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.04234, and p value is 0.7680

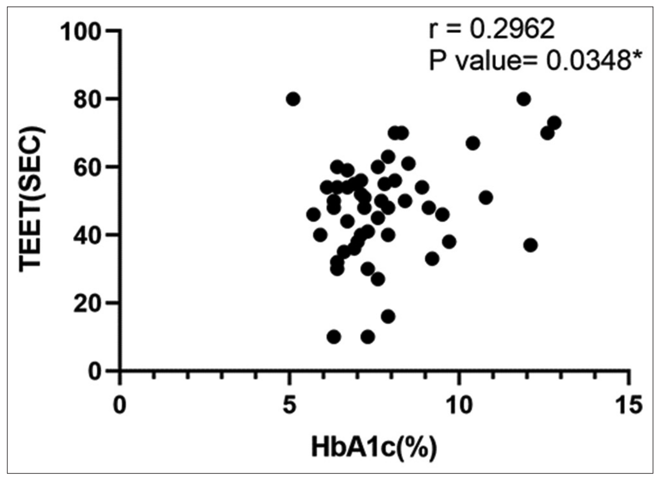

Figure 3d: The graph represents the correlation between HbA1c levels with TEET in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.2962, and p value is 0.0348. *p value $\leq$ 0.05 is significant

Moreover, this is the group in which lifestyle intervention and modification can attain maximum positive effects, as in elderly diabetic group, there already exists marked sarcopenia because of aging along with comorbidities because of diabetes.[14] The statistics compiled as part of this study show that the presence of T2DM has a considerable impact on cardiac autonomic function which has been assessed by a more recently developed method, namely the HRV test. This significant decrease in HRV parameters [Tables 2 and 3] reveals the increase in sympathetic tone and decrease in parasympathetic tone and establishes the presence of cardiac autonomic neuropathy (CAN) in middle-aged, newly diagnosed T2DM group also. Diabetic CAN is a serious complication that affects one-third of patients with T2DM and is associated with a fivefold increased risk of developing cardiovascular mortality.[15] CAN is often underdiagnosed because of the lack of standardized diagnostics, whereas cardiovascular mortality associated with CAN has been found to be the primary cause of death in patients with T2DM.[16,17] This increase in sympathetic tone in T2DM in turn effects the function of skeletal muscle.

Three major factors, namely strength, power, and endurance, determine the performance of skeletal muscles. Accordingly, muscle performance was assessed using muscle flexibility and core endurance tests.

In this study, a significant decrease in hamstring muscle flexibility was observed, assessed by active knee extension test in both lower limbs in T2DM patients compared with that in the control group [Table 4]. This indicates that there is decreased muscle flexibility even in middle-aged group, probably because of muscle and neuromuscular impairments in them. As observed in other recent studies also, stating sarcopenia as a prevalent chronic complication in diabetes.[18] This leads to changes in fiber distribution, changes in GLUT4 density, mitochondria, intramuscular fat, and metabolic inflexibility which are

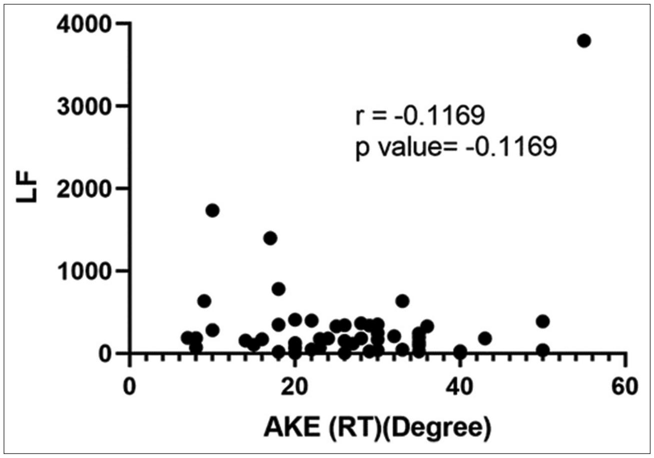

Figure 4a: The graph represents the correlation between AKE (RT) test and LF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is -0.1169, and p value is 0.1169

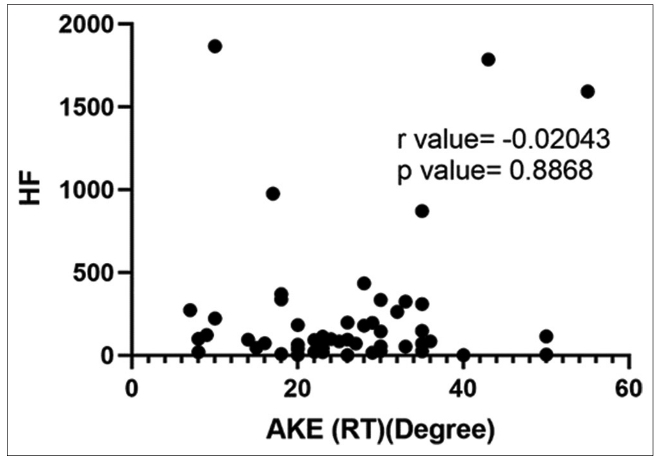

Figure 4b: The graph represents the correlation between AKE (RT) test and HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is -0.02043, and p value is 0.8868

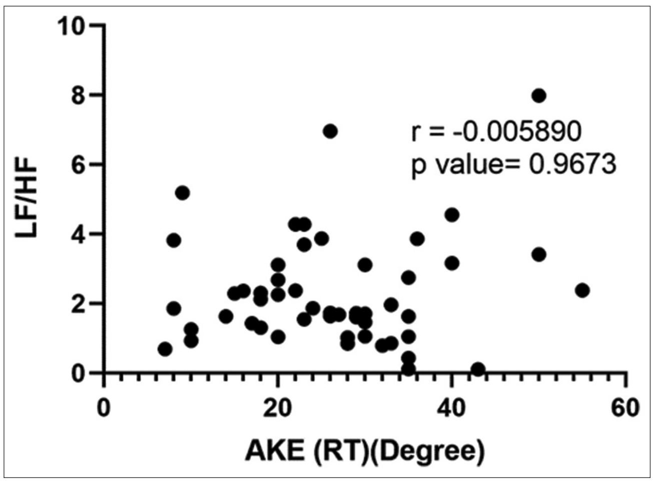

Figure 4c: The graph represents the correlation between AKE (RT) test and LF/HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is -0.005890, and p value is 0.9673

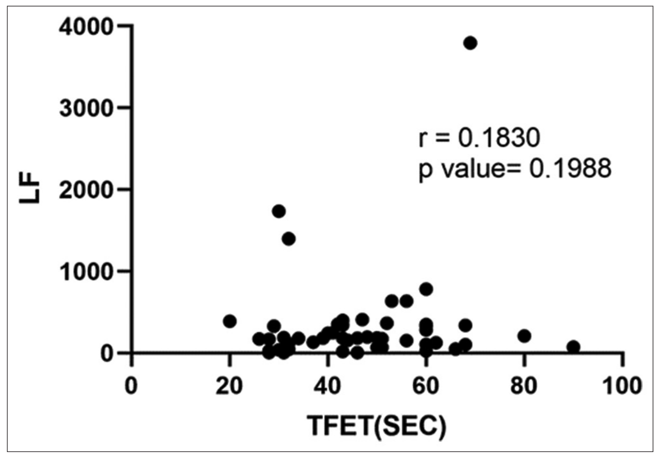

Figure 5a: The graph represents the correlation between TFET and LF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.1830, and p value is 0.1988

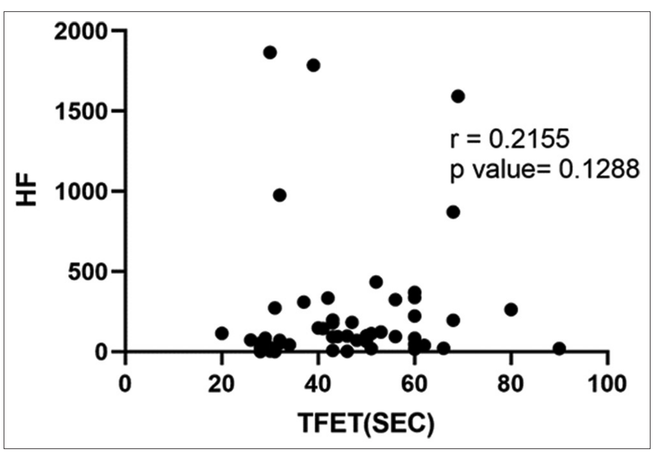

Figure 5b: The graph represents the correlation between TFET and HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.2155, and p value is 0.1288

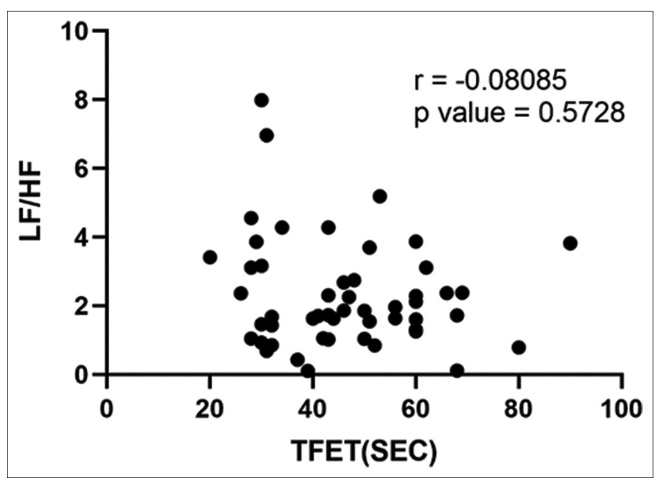

Figure 5c: The graph represents the correlation between TFET and LF/HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.08085, and p value is 0.5728

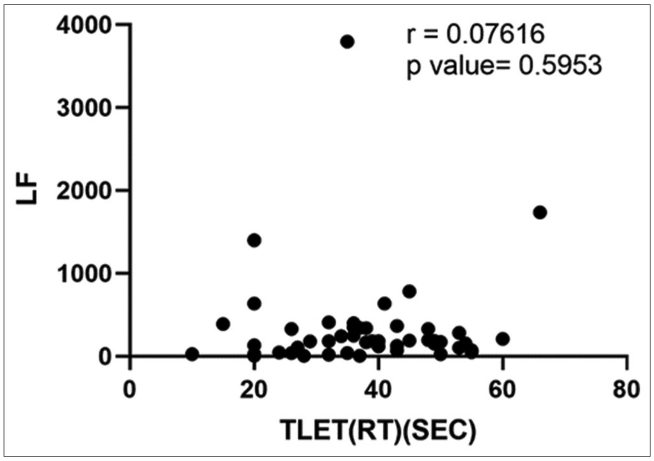

Figure 5d: The graph represents the correlation between TLET (RT) and LF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.07616, and p value is 0.5953

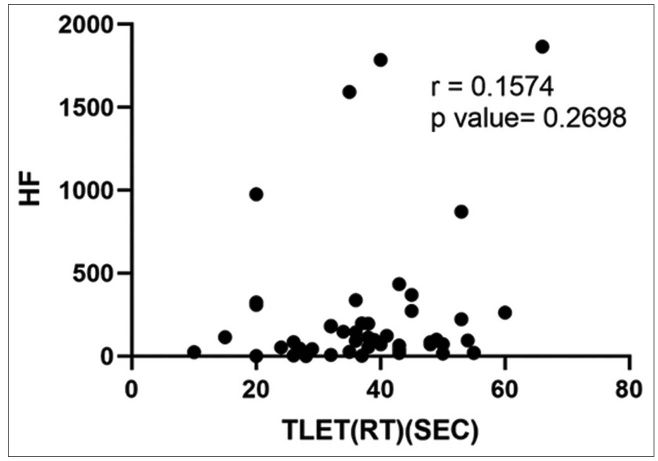

Figure 5e: The graph represents the correlation between TLET (RT) and HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.1574, and p value is 0.2698

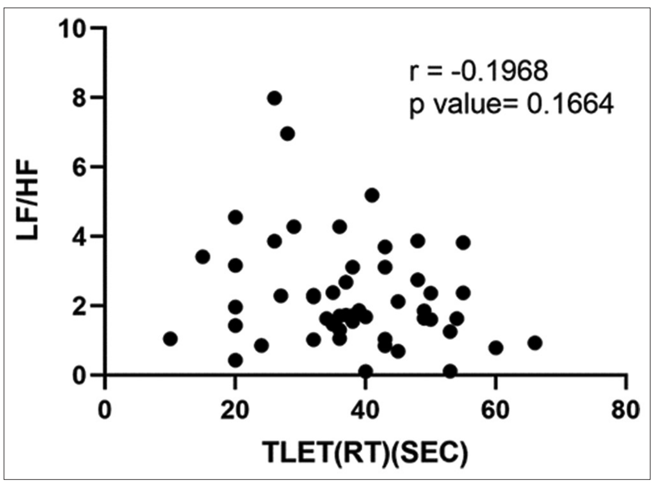

Figure 5f: The graph represents the correlation between TLET (RT) and LF/HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is -0.1968, and p value is 0.1664

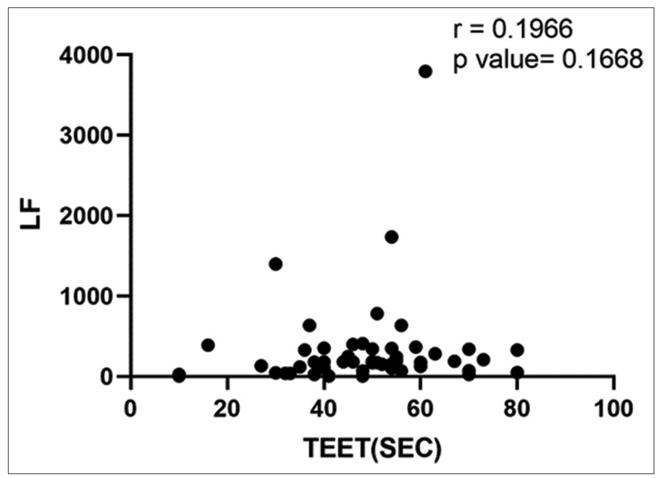

Figure 5g: The graph represents the correlation between TEET and LF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.1966, and p value is 0.1668

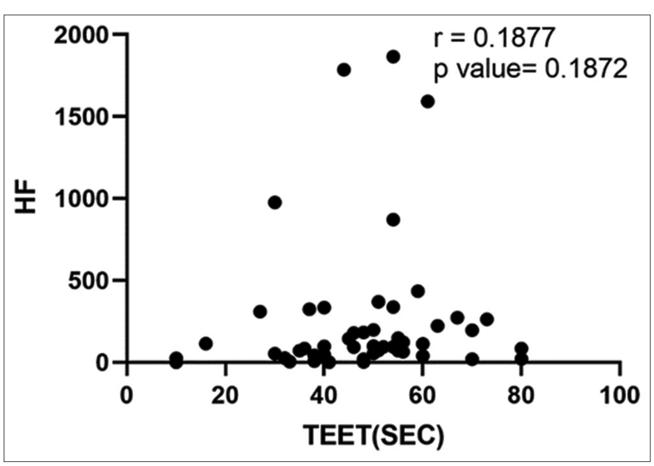

Figure 5h: The graph represents the correlation between TEET and HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.1877, and p value is 0.1872

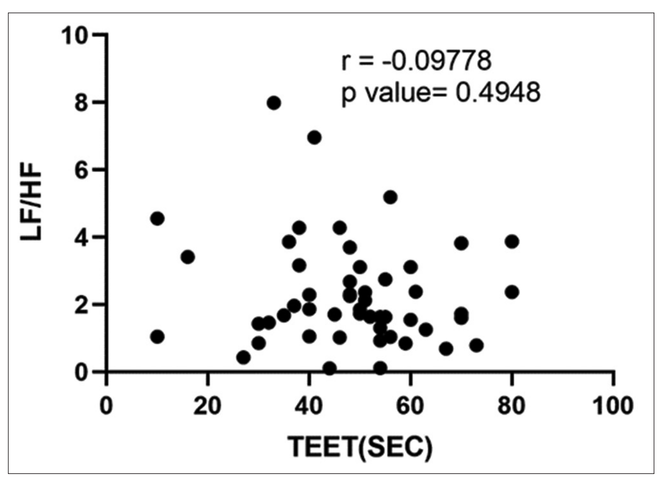

Figure 5i: The graph represents the correlation between TEET and LF/HF in T2DM patients. Statistical significance of the correlations was calculated using Spearman's correlation test. The r is 0.09778, and p value is 0.4948

muscular factors that cause further weakness and blood glucose dysregulation.[19]

This study assessed the musculoskeletal component of trunk muscle endurance. The findings indicate that patients with T2DM have a significant reduction in core muscle endurance compared to normal healthy subjects [Table 5]. These findings are consistent with other studies also showing that T2DM patients are known to have markedly reduced muscle strength and an increased risk of sarcopenia.[20]

The decrease in muscle performance in T2DM as observed in this case is a pathological feature of sarcopenia that occurs with aging but diabetes accelerates this process. This happens because in T2DM, protein, and lipid metabolism are disrupted, leading to a decrease in flexibility with the progression of T2DM because of the loss of elasticity in the connective tissue surrounding the muscles, which undergoes a normal shortening process. The decrease in joint range of motion and muscle flexibility in patients with T2DM may be due to the formation of associated molecular cross-linking in collagen molecules that can potentially alter the mechanical characteristics of collagen at the cellular level. The increase in collagen crosslinking alters the mechanical properties of these tissues, with a decrease in elasticity and tensile strength and an increase in mechanical stiffness, causing the joint to lose flexibility.[19] The cross-linking of advanced glycation end-products (AGEs) contributes to the rigidity of connective tissues and increases when a person is hyperglycemic.[21]

In this study, no significant correlation was observed between HRV parameters [Figure 1a-c], muscle flexibility [Figure 2a and b], core muscle endurance [Figure 3a-d], and HbA1c levels. This could be explained by the fact that the T2DM patients included in the study mostly have satisfactory blood control and duration of T2DM is also less than 5 years. Also, in other studies like, it has been shown that correlation between LF, RMSSD, and LF/HF in patients with poorly controlled type 2 diabetes mellitus was not significantly different.[22] However, in a few studies, a significant impact of HbA1c levels was observed on muscle flexibility in T2DM patients.[23]

In this study, the correlation between the hamstring muscle flexibility on the right side and the respective frequency domain parameters (LF, HF, and LF/HF) was not significant [Figure 4a-c]. The association between core muscular endurance measures (TFET, TLET, and TEET) and respective HRV parameter frequency domains (LF, HF, and LF/HF) was also not significant in this study [Figure 5a-i].

However, many other studies have documented that heart failure is typically accompanied by skeletal muscle abnormalities that contribute to exercise intolerance and poor health-related quality of life, usually observed in these patients, indicating a relationship between cardiac autonomic dysfunction and muscle performance.[8]

One study has explained the relationship between cardiac autonomic neuropathy and diabetes. A higher resting total power is associated with exercise capacity, which may reflect a "healthier" cardiac autonomic system. It has been suggested that a strong and efficient parasympathetic nervous system (PNS), but not an overactive sympathetic nervous system (SNS), is the basis of a well-balanced and adaptable cardiac autonomic system.[24] During exercise, a shift in the balance of cardiac autonomic modulation (PNS/SNS ratio) from ~4:1 at rest to ~1:4 at maximal exercise is required to increase HR.[25] The degree of the association between muscle performance and HRV was not determined in this study. This was because of few limitations associated with this study. The sample size of the patient group was small, and most of the T2DM patients included in this study had good glycemic control and a shorter duration of disease. In addition, the HRV parameters were recorded for a short duration. Also, cardiorespiratory fitness measurements should also be investigated in future studies. Despite these limitations, this is notable for being the first of its type in this region to assess the muscle performance in middle-aged type 2 diabetes mellitus and to investigate the relationship between muscle performance and cardiac autonomic function in this region. No specific globally followed parameters are present for assessing muscle performance, though decreased muscle performance and cardiac autonomic neuropathy are two very debilitating comorbidities of T2DM. Also, most of the studies to date are done on muscle performance in elderly or neuropathic T2DM patients.[26,27] In this study, middle-aged, satisfactory blood glucose control and newly diagnosed T2DM patients are recruited. The confounding effect of age, sex, and BMI are mitigated by taking age-, sex-, and BMI-matched control group. In future studies, it would be desirable to strengthen these parameters and evaluate their association.

Conclusion

The findings of this study suggest a significant decrease in muscle performance and the presence of cardiac autonomic impairment in middle-aged T2DM patients. This study puts emphasis on the dire need of forming a proper exercise regimen for diabetes patients at an early stage, incorporating strength-training and endurance exercises to improve muscle performance in T2DM patients, as well as the incorporation of yoga exercises to improve cardiac autonomic function in T2DM patients. A positive corollary is that early screening and diagnosis of decreased muscle performance and cardiac autonomic neuropathy in younger diabetes patients would enable timely preventive measures to maintain glucose regulation and thus stem the associated progressive degeneration. This will improve the quality of life and morbidity of such middle-aged patients, especially since they have a comparatively longer lifespan ahead.

Consent

Informed consent was obtained from each patient prior to the study, and all procedures were explained to the patient.

Ethical clearance

This case–control study was conducted in the Department of Physiology, HIMSR, Jamia Hamdard, New Delhi, in collaboration with the Department of Medicine, HAHC Hospital, New Delhi, after obtaining ethical clearance from the Institutional Ethical Committee of Jamia Hamdard University, New Delhi, India.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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