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Assessment of Plantar Flexors Strength and Range of Motion in Diabetic and Non-Diabetic Individuals

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ABSTRACT

Background Diabetes is a chronic condition that can accelerate muscle aging, leading to weakness, reduced strength, and diminished range of motion (ROM). The excess glucose in the blood can damage nerves and blood vessels, impairing muscle function and regeneration.

Objective: To assess the strength and ROM of plantar flexors in diabetic and non-diabetic individuals and evaluate the impact of diabetes on these parameters.

Methods: A case-control study was conducted on 80 diabetic and 80 non-diabetic individuals aged 40 to 65 years at Akhtar Saeed Medical and Dental College, Lahore. Plantar flexor strength was measured using a heel rise test, and ROM was assessed with a goniometer. Data were analyzed using SPSS version 25, with chi-square tests and odds ratios used to determine associations.

Results: Diabetic individuals showed a significant association between strength and ROM (p = 0.00) with chi-square values of 47.19 and 52.77 for right and left plantar flexors, respectively. However, the odds ratio of 0.22 indicated diabetes was not a strong risk factor for reduced strength.

Conclusion: While diabetes is significantly associated with reduced plantar flexor strength and ROM, it is not a strong independent risk factor for these impairments.

INTRODUCTION

Diabetes is a chronic metabolic disease characterized by elevated levels of blood glucose, which over time can lead to severe complications affecting various body systems, including the cardiovascular, nervous, and musculoskeletal systems (1). The condition predominantly occurs in adults due to insulin resistance or insufficient insulin production, with a prevalence of approximately 422 million individuals globally, most of whom reside in low- and middle-income countries, and it accounts for about 1.5 million deaths annually (2). Historical records indicate that diabetes has been a recognized ailment for over 3000 years, as documented in ancient Egyptian texts. Diagnostic criteria for diabetes involve fasting blood sugar levels, with a range of 100 to 125 mg/dL indicating prediabetes and values of 126 mg/dL or higher confirming a diagnosis of diabetes (3).

Diabetes accelerates the natural process of muscle aging, such as sarcopenia, through mechanisms including oxidative stress, mitochondrial dysfunction, and insulin resistance (4). Adequate skeletal muscle strength is crucial for maintaining physical function, and a decline in muscle strength often signals physical limitations (5). The impact of diabetes on muscle function is particularly evident in the lower limbs, where it increases the risk of falls and associated injuries, which can further compromise mobility and lead to a reduction in quality of life (6). Among the lower limb muscles, the plantar flexors, which include the gastrocnemius, soleus, and plantaris (collectively known as the Achilles tendon), play a pivotal role in maintaining knee and ankle stability and are essential for effective locomotion (7).

Peripheral neuropathy, a common complication of diabetes characterized by nerve damage, frequently affects the distal extremities, including the feet, and leads to muscle weakness, including in the plantar flexors (8). This weakness can impair balance, gait, and overall functional abilities, contributing to difficulties in everyday activities such as walking and climbing stairs (9). Moreover, diabetes-related reductions in plantar flexor strength have been associated with decreased joint proprioception and increased joint stiffness, which further exacerbate functional impairments (10). Regular physical activity targeting the calf muscles and meticulous blood glucose control are crucial for managing and potentially mitigating the impact of peripheral neuropathy on muscle strength in individuals with diabetes (11).

Functional assessment of the plantar flexor muscles, such as the gastrocnemius, often involves tasks like heel raises, which test the muscle's ability to generate force repeatedly. This activity also highlights the biomechanical shift that occurs during plantar flexion, where the axis of rotation moves from the ankle to the metatarsophalangeal joints, enhancing the moment arm and thus the muscle's efficiency (12). However, despite the muscle's contraction, the center of gravity of the body is elevated only partially, indicating a complex interplay between muscle mechanics and functional output (13). Various methods are employed to assess muscle strength, including manual muscle testing (MMT), handheld dynamometers, and isokinetic testing.

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MMT is frequently utilized in clinical settings due to its ease of administration and cost-effectiveness, despite its limitations in providing subjective data that can vary based on the examiner's strength (14).
The present study aims to assess the strength and range of motion (ROM) of plantar flexors in diabetic and non-diabetic individuals, recognizing the significant role these muscles play in mobility and stability. Previous studies have shown varying results regarding the impact of diabetes on muscle strength, with some indicating significant impairments while others report minimal differences between diabetic and non-diabetic populations (15, 16). Understanding the extent to which diabetes affects plantar flexor strength and ROM can provide insights into the development of targeted interventions to preserve function and enhance quality of life in affected individuals. This study specifically evaluates these parameters in a middle-aged population, providing valuable data that may inform clinical practice and guide recommendations for exercise and management strategies in individuals with diabetes.

MATERIAL AND METHODS

This case-control study was conducted at Akhtar Saeed Medical and Dental College, Lahore, from May to December 2023, focusing on diabetic and non-diabetic individuals aged 40 to 65 years. This age range was chosen to represent the middle-aged population, who are more likely to exhibit the musculoskeletal changes associated with diabetes. Participants were included if they had been diagnosed with diabetes for 10 or more years and were on oral hypoglycemic agents, insulin, or both. Exclusion criteria comprised individuals with foot ulcers, lower limb deformities, amputations, foot drops, those who were wheelchair-bound, bedridden, or unconscious, as these conditions could independently affect muscle strength and range of motion. Ethical approval for the study was obtained from the Ethical Review Committee of Akhtar Saeed Medical and Dental College, Lahore, in compliance with the Declaration of Helsinki, and all participants provided written informed consent prior to their inclusion in the study.
The sample size was calculated using the Rao Soft sample size calculator to ensure sufficient power to detect statistically significant differences between groups (19). A non-probability convenience sampling method was employed for participant recruitment. Data were collected on plantar flexor strength and range of motion (ROM) for both feet. Plantar flexor strength was assessed using the heel rise test as part of manual muscle testing (MMT), wherein participants were asked to stand on one leg while keeping the other leg off the ground, performing at least 25 heel rises through the full ROM without resting or experiencing fatigue. Participants were permitted to use a nearby wall for balance to prevent falls. Based on the number of heel rises completed, participants were assigned a grade on the MMT scale, ranging from poor to normal strength (15, 17).
ROM of the ankle plantar flexion for both the right and left ankles was measured using a goniometer. Participants were positioned in a long sitting posture, with the goniometer's fulcrum placed on the lateral malleolus, the stationary arm aligned with the fibula, and the moving arm aligned with the lateral border of the foot. Measurements were taken by trained personnel and documented on standardized forms to maintain consistency and accuracy (16, 18).
Data were analyzed using SPSS version 25. Descriptive statistics, including means and standard deviations, were calculated for continuous variables, while frequencies and percentages were used for categorical variables. The association between plantar flexor strength and ROM, as well as comparisons between diabetic and non-diabetic groups, were evaluated using chi-square tests, and odds ratios were calculated to determine the likelihood of reduced strength and ROM in diabetic individuals compared to non-diabetics. An odds ratio of less than 1 indicated that diabetes was not a significant risk factor for reduced plantar flexor strength or ROM. Statistical significance was set at a p-value of less than 0.05. All analyses were performed with a 95% confidence interval to ensure the robustness of the findings. The study's findings were presented in tabular form to facilitate clear and concise interpretation.

RESULTS

The data presented in Table 1 illustrates the association between the range of motion (ROM) and muscle strength of plantar flexors in both diabetic and non-diabetic individuals.

Diabetics

For diabetic participants, there was a notable distribution of muscle strength categories across different ROM groups. For the right plantar flexors, the ROM range of 11-20 degrees showed that most individuals fell into the 'poor' strength category (8 out of 15), with a significant chi-square value of 47.19 and a p-value of 0.00, indicating a strong association. Similarly, the left plantar flexors in diabetics showed that within the ROM range of 11-20 degrees, 'poor' strength was again the most common (8 out of 12), with a chi-square value of 52.77 and a p-value of 0.00, highlighting a significant correlation between ROM and strength in this population.

Table 1: Association of ROM with Muscle Strength in Diabetics

Strength of Right Plantar Flexors	Poor	Fair	Good	Normal	Total	Chi-Square	P-Value
Right ROMs 11-20	8	3	4	0	15	47.19	0.00
Right ROMs 21-30	3	5	5	0	13		
Right ROMs 31-40	3	3	25	1	32		
Right ROMs 41-50	0	2	10	8	20		
Total	**14**	**13**	**44**	**9**	**80**		
Left ROMs 11-20	8	1	3	0	12	52.77	0.00
Left ROMs 21-30	3	6	5	0	14		

Left ROMs 31-40	3	4	23	2	32
Left ROMs 41-50	0	2	13	7	22
Total	14	13	44	9	80

Non-Diabetics

For non-diabetic individuals, the association between ROM and strength also demonstrated significant patterns. In the right plantar flexors, 34 participants had a ROM of 41-50 degrees, with the majority exhibiting 'normal' strength (24 out of 34), which contributed to a chi-square value of 38.92 and a p-value of 0.00, confirming a significant association. The left plantar flexors followed a similar trend, with most non-diabetic individuals in the ROM range of 41-50 degrees showing 'normal' strength (24 out of 37), resulting in a chi-square value of 41.24 and a p-value of 0.00.

Table 2: Association of ROM with Muscle Strength in Diabetics

Strength of Right Plantar Flexors	Poor	Fair	Good	Normal	Total	Chi-Square	P-Value
Right ROMs 11-20	2	0	1	0	3	38.92	0.00
Right ROMs 21-30	4	3	7	1	15		
Right ROMs 31-40	5	4	14	5	28		
Right ROMs 41-50	0	0	10	24	34		
Total	**11**	**7**	**32**	**30**	**80**		
Left ROMs 11-20	3	0	2	0	5	41.24	0.00
Left ROMs 21-30	3	4	5	0	12		
Left ROMs 31-40	5	2	13	6	26		
Left ROMs 41-50	0	1	12	24	37		
Total	**11**	**7**	**32**	**30**	**80**		

Table 2 explores the association of diabetes with ankle plantar flexor weakness, comparing diabetic and non-diabetic groups. Among diabetics, only 10 out of 80 participants had 'normal' muscle strength (Grade 5), whereas the remaining 70 exhibited less than Grade 5 strength. This association was statistically significant, with a chi-square value of 14.46 and a p-value of 0.00. The odds ratio of 0.22 indicates that diabetics were significantly less likely to have normal plantar flexor strength compared to non-diabetics, suggesting that diabetes is associated with a higher prevalence of muscle weakness.

Table 2: Association of Diabetes with Ankle Plantar Flexors Weakness

Strength	Normal Grade 5	Less than Grade 5	Total	Odd Ratio	Chi-Square	P-Value
Diabetes (Yes)	10	70	80	0.22	14.46	0.00
Diabetes (No)	31	49	80			

Table 3 focuses on the association between diabetes and reduced ROM in the right foot's plantar flexors. Among diabetic individuals, 34 out of 80 had a normal ROM (above 40 degrees), while 46 had an abnormal ROM (below 40 degrees). The chi-square value of 4.22 and a p-value of 0.04 indicate a significant association, although the odds ratio of 0.52 suggests that diabetes does not strongly predispose individuals to reduced ROM in the right plantar flexors.

Table 3: Association of Diabetes with Reduced Ankle Plantar Flexion ROM of Right Foot

Right Range of Motion	Normal Above 40	Abnormal Below 40	Total	Odd Ratio	Chi-Square	P-Value
Diabetes (Yes)	34	46	80	0.52	4.22	0.04
Diabetes (No)	47	33	80			

Table 4 presents data on the association between diabetes and reduced ROM in the left foot's plantar flexors. In the diabetic group, 33 out of 80 participants had normal ROM (above 40 degrees), while 47 had reduced ROM (below 40 degrees). This association was statistically significant, as indicated by a chi-square value of 8.12 and a p-value of 0.00.

Table 4: Association of Diabetes with Reduced Ankle Plantar Flexion ROM of Left Foot

Left Range of Motion	Normal Above 40	Abnormal Below 40	Total	Odd Ratio	Chi-Square	P-Value
Diabetes (Yes)	33	47	80	0.39	8.12	0.00
Diabetes (No)	51	29	80			

The odds ratio of 0.39 further emphasizes that while there is a significant association between diabetes and reduced ROM, it does not constitute a strong risk factor for this condition in the left plantar flexors.

Overall, the data consistently demonstrate significant associations between diabetes, muscle strength, and ROM in plantar flexors, with chi-square values consistently indicating strong statistical relationships. However, the odds ratios suggest that diabetes alone may not be a strong independent risk factor for reduced strength and ROM, as these values remain below 1 across all comparisons.

DISCUSSION

The present study demonstrated a significant association between diabetes and both plantar flexor strength and range of motion (ROM) in diabetic and non-diabetic individuals, suggesting that diabetes may contribute to alterations in muscle function. Although the odds ratios indicated that diabetes is not a strong independent risk factor for reduced strength and ROM, the findings underscore the importance of monitoring and managing these parameters in diabetic patients to prevent further functional decline. The results align with previous studies that have reported muscle weakness and impaired joint function in individuals with diabetes, particularly those with long-standing or poorly controlled disease (20).

Henning Andersen et al. (2004) found reduced maximal isokinetic muscle strength in diabetic patients, specifically in the ankle extensors and flexors, which corroborates the current study's observation of a significant association between diabetes and reduced plantar flexor strength. However, unlike the present study, Andersen's work did not find a direct relationship between diabetes and specific muscle strength, highlighting the variability in muscle impairment across different studies (20). Similarly, the findings of Salsich et al. (2000) indicated that muscle stiffness and strength are interrelated in diabetic patients with polyneuropathy, but they did not establish a clear correlation between stiffness and ROM. In contrast, the current study demonstrated a significant association between strength and ROM, suggesting that muscle function in diabetic patients may be influenced by factors beyond stiffness, such as proprioceptive deficits or alterations in muscle-tendon dynamics (21).

Andreassen et al. (2006) reported a relationship between the decline in muscle strength at the ankle and neuropathy severity in diabetic patients, which supports the current study's findings of reduced strength in diabetic individuals. However, the present study's odds ratios suggest that while diabetes is associated with strength reduction, it does not serve as a definitive risk factor for this impairment. This discrepancy could be attributed to differences in study populations, assessment methods, or the inclusion of patients with varying durations and severities of diabetes (22). Furthermore, Van Eetvelde et al. (2020) found that healthy controls had superior muscle endurance, strength, and power compared to diabetic individuals, emphasizing the broader impact of diabetes on musculoskeletal health. The present study extends these findings by quantifying the specific associations with plantar flexor strength and ROM, thus providing a more nuanced understanding of the functional implications of diabetes (23).

The study had several strengths, including a clear definition of inclusion and exclusion criteria, the use of validated assessment tools such as the heel rise test and goniometer, and a robust statistical analysis that accounted for potential confounders. However, there were also limitations. The cross-sectional design precluded the establishment of causality, and the use of non-probability convenience sampling may have introduced selection bias, potentially limiting the generalizability of the findings. Additionally, the reliance on manual muscle testing, although practical in clinical settings, could have introduced variability due to its subjective nature. Future studies could benefit from incorporating more objective measures of muscle function, such as isokinetic dynamometry, and exploring longitudinal designs to assess changes over time.

Given the significant associations observed, it is recommended that clinicians consider regular assessments of plantar flexor strength and ROM in diabetic patients as part of routine care. Interventions such as targeted exercise programs, aimed at improving calf muscle strength and flexibility, could be beneficial in mitigating the functional impairments associated with diabetes. Moreover, optimizing glycemic control and managing comorbidities such as peripheral neuropathy may further enhance muscle function and reduce the risk of mobility-related complications. Future research should explore the mechanistic pathways linking diabetes to muscle dysfunction, including the roles of inflammation, oxidative stress, and vascular insufficiency, to better tailor therapeutic strategies.

Overall, the study contributes valuable insights into the functional implications of diabetes on plantar flexor strength and ROM, highlighting the need for comprehensive management approaches that address both metabolic and musculoskeletal health in this population. While diabetes was not identified as a strong risk factor, its significant association with muscle impairment underscores the importance of ongoing research and clinical vigilance in this area.

CONCLUSION

The study concluded that there is a significant association between diabetes and reduced plantar flexor strength and range of motion (ROM) in both diabetic and non-diabetic individuals; however, diabetes was not found to be a strong independent risk factor for these impairments, as indicated by odds ratios less than one. These findings suggest that while diabetes contributes to muscle weakness and joint limitations, other factors may also play a critical role. From a healthcare perspective, regular assessment and targeted interventions, such as strength training and flexibility exercises, should be considered to maintain functional mobility and prevent complications in diabetic patients. This highlights the importance of integrated care approaches that encompass both metabolic and musculoskeletal management to enhance overall quality of life and reduce the risk of mobility-related issues in this population.

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