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REVIEW ARTICLE

Sonographic Evaluation of Tibial and Common Peroneal Nerves in Patients with Long Standing Diabetes

Sukhdev Joshi[1*], Vaishali Upadhyaya[2], A K Pandey[3], Richa Srivastava[4], Arun Sachdeva[5]

[1]*Department of Radiology, Vivekananda Polyclinic & Institute of Medical Sciences, Lucknow, UP, India*
[2]*Department of Radiodiagnosis, Vivekananda Polyclinic & Institute of Medical Sciences, Lucknow, UP, India*
[3]*Department of Neurology, Vivekananda Polyclinic & Institute of Medical Sciences, Lucknow, UP, India*
[4]*Department of Plastic Surgery, Vivekananda Polyclinic & Institute of Medical Sciences, Lucknow, UP, India*
[5]*Department of General Medicine, Vivekananda Polyclinic & Institute of Medical Sciences, Lucknow, UP, India*

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***Correspondence:**
Sukhdev Joshi
joshisukhdev11@gmail.com

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Abstract

Introduction: Ultrasound is a helpful imaging tool to determine the location, extent, type of lesion as well as the presence of nerve swelling and inflammation in patients with diabetic peripheral neuropathy. The study highlights the significant impact of long-standing diabetes on the tibial and common peroneal nerves, underscoring the importance of sonographic evaluation in diabetic patients.

Method: This Cross-sectional observational study was carried out in the Radiodiagnosis department of Vivekanand Polyclinic & Institute of Medical Sciences, focusing on 48 patients having long standing diabetes (>10 years). Ultrasonography was performed with Siemens Acuson NX3 Elite using a linear transducer (4–12 MHz) in patients meeting inclusion criteria.

Results: The study's correlation analysis of sonographic findings and clinical parameters revealed that there is strong positive correlation between the duration of disease and CSA and MTNF of the Tibial nerve, moderate positive correlation between Blood sugar levels and all nerve parameters, strong and moderate correlations between HbA1c levels and all nerve parameters, with the highest correlation observed for the CSA of the Tibial nerve and lastly moderate correlation between clinical features and all nerve measures, most notably with MTNF of the Tibial nerve

Conclusion: Ultrasound is a non-invasive, low cost and real-time imaging technique to evaluate peripheral nerves in diabetic patients to identify changes in these nerves early so that healthcare providers can implement more targeted interventions to mitigate the progression of neuropathy.

Introduction

Prevalence of diabetes in India was reported to be 69.2 million (2015), with over 50% of cases remaining undetected, by the World Health Organisation.[1] Approximately 30% of individuals with diabetes mellitus develop diabetic peripheral neuropathy, which is the significant complication of the disease.[2] The development of diabetic polyneuropathy is significantly influenced by inadequate glycemic control. The

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initiation of neuropathy is precipitated by osmotic enlargement of the nerves caused by damage to the myelin sheath and axons.[3] Foot symptoms such as tingling, numbness, or prickling are frequently reported by patients. Early diagnosis, detection, and treatment of this condition are beneficial due to its high prevalence among diabetic patients.[4]

Ultrasound (US) is a useful imaging tool to evaluate musculoskeletal system. US have several advantages like low cost, accessibility, portability, non-invasiveness, and multiplanar imaging. One of its most important diagnostic advantages over other techniques is its real-time imaging capability, allowing for dynamic evaluation of the musculoskeletal system.[4, 5]

US can be used to determine the location, extent, and the type of lesion. It can also detect presence of nerve swelling and inflammation. Major peripheral nerves in the extremities, such as the median, ulnar, radial, sciatic, Common Peroneal nerve and posterior Tibial nerves can be examined using conventional US performed with 5 to 12 MHz probes.[5] In US, peripheral nerves are seen as hypoechoic neuronal fascicles surrounded by echogenic connective tissue.[6] Ultrasonography of the Tibial and Common Peroneal nerve is very helpful tool for detecting diabetic neuropathy. There is no radiation exposure or discomfort to patient.

The study was aimed to do sonographic evaluation of Tibial and Common Peroneal nerve in patients with longstanding diabetes more than 10-years.

Material and methods

The cross sectional observational study was carried out in the Radiodiagnosis department of a tertiary care hospital for a duration of 18-months. It involved 48 patients having long standing diabetes (>10 years) referred to the Department of Radio Diagnosis. Sonographic evaluation of Tibial and Common Peroneal nerves was done in these patients.

After receiving ethical clearance from the institute's ethical committee, all patients meeting specified inclusion criteria (those having type-2 Diabetes for more than 10-years and providing written consent for participation in the study) were included. Socio -demographic information was collected via a questionnaire. Examination was carried out for every patient after obtaining consent.

Technique

Ultrasonography was performed with Siemens Acuson NX3 Elite using a linear transducer (4–12 MHz). For examination of Tibial nerve, Ultrasonography was performed with the patient lying in a lateral position for an easy assessment of the medial aspect of the ankle and distal leg. Common peroneal nerve was examined at the level of fibular head with subject's leg slightly flexed at knees in the lateral position with affected leg up. For Tibial nerve, the cross-sectional area and maximum thickness of nerve fascicles were recorded 3 cm above the medial malleolus and of Common Peroneal nerves at the fibular head. The cross-sectional area was calculated by manual tracing. The maximum thickness of the nerve fascicle was calculated by the largest anteroposterior dimension of the largest hypoechoic area in the short-axis view of nerves.

Demographic information including age, sex, duration of the disease, blood sugar, and HbA1c levels were recorded for all patients. The cross-sectional area (CSA) and maximum thickness of nerve fascicles (MTNF) were correlated with the duration of the disease, clinical features, blood sugar, and HbA1c levels.

Statistical Analysis

Data was entered in Microsoft Excel and analyzed using statistical software SPSS version 26 (SPSS Inc., Chicago, IL, USA). The dichotomous and continuous variables were presented in Mean±SD and were analyzed using Student *t-tests*, respectively. Correlation analysis was used. To compare the means between the two or more groups, analysis by Student *t-test* was used. A *p-value* of < 0.05 or 0.001 was regarded as significant.

Results

We included a total of 48 patients having long standing diabetes (>10 years). The findings of the study are outlined in tables 1 to 8.

Table 1: Demographic Characteristics of study participants

DEMOGRAPHIC CHARACTERISTIC	NUMBER [N=48]	PERCENTAGE
AGE (years)		
Mean ± SD	47.78 ± 6.63	-
30–40	2	4.17%
41–50	17	35.42%
50–60	23	47.92%
>60	6	12.50%
GENDER		
Male	31	64.58%
Female	17	35.42%
BMI (Kg/m^2)		
Mean ± SD	28.84 ± 2.53	–
Normal (18.5–24.9)	7	14.58%
Overweight (25–29.9)	18	37.50%
Obese (≥30)	23	47.92%

The mean age of the patients was 47.78 years with a standard deviation (SD) of 6.63 years. Majority of patients were in age group between 50–60 years, followed by between 41–50 years and least in age group between 30–40years.

In study majority were males 64% (n = 31). Male to female ratio was 1.8:1.

Regarding BMI categories, 14.58% of the patients had a normal BMI (18.5–24.9), 37.50% were overweight (25–29.9), and 47.92% were obese (BMI ≥30).

Table 2: Clinical Characteristics of Study Participants

	NUMBER [N=48]	PERCENTAGE
DURATION OF DIABETES (years)		
Mean ± SD	18.52 ± 5.65	-
10–15 Yrs	27	56.25%
15.1–20 Yrs	15	31.25%
>20 Yrs	6	12.50%
SYMPTOMS		
Pain	33	68.75%
Swelling	29	60.41%
Numbness	15	31.25%
Loss of Sensation	9	18.75%

Table 3: Blood Sugar Levels of Study Participants

Blood Sugar (mg/dl)	MEAN [N=48]	%
	241.51 ± 76.84	
150–250	22	45.83%
250–350	17	35.42%
>350	9	18.75%

The mean duration of diabetes among the patients was 18.52 years (SD ± 5.65). Specifically, 56.25% have had diabetes for 10–15 years, 31.25% for 15.1–20 years, and 12.50% for more than 20 years. Symptomatically, most common presenting symptom was pain followed by swelling, numbness and loss of sensation.

The mean blood sugar level among the 48 patients with long-standing diabetes was 241.51 mg/dL (SD ± 76.84). In terms of distribution, majority of patients had blood sugar levels between 150 –250 mg/dL, followed by 250–350 mg/dL and 18.75% had levels exceeding 350 mg/dL

The mean HbA1c level for the 48 patients with long-standing diabetes was 8.21% (SD ± 1.32). The distribution of HbA1c levels was as follows: 6.25% of patients had HbA1c levels below 7%, 54.17% had levels between 7–8%, 20.83% had levels between 8.1–9%, 16.67% had levels between 9.1–10%, and 2.08% had levels above 10%.

Table 4: HbA1c Levels of Study Participants

HbA1c Levels (%)	MEAN [N=48]	%
	8.21 ± 1.32	
<7	3	6.25%
7-8	26	54.17%
8.1–9	10	20.83%
9.1–10	8	16.67%
>10	1	2.08%

Table 5: Prevalence of Neuropathy Among Study Participants

NEUROPATHY	*n*	%
Yes	28	58.33%
No	20	41.67%

Out of the 48 patients with long-standing diabetes, 58.33% (*n* = 28) were diagnosed with neuropathy, while 41.67% (*n* = 20) didn't have neuropathy.

For the Tibial nerve, the mean cross-sectional area (CSA) was 12.47 mm^2 (SD ± 3.45). Among these, 45.83% had a normal CSA (<10.5 mm^2), while 54.17% had an enlarged CSA (≥10.5 mm^2). The mean maximal thickness of the nerve fascicles (MTNF) for the Tibial nerve was 5.67 mm (SD ± 0.28), with 41.67% having a normal MTNF (<3 mm) and 58.33% having an enlarged MTNF (≥3 mm).

Table 6: Sonographic Findings among study participants

Characteristic	Mean/N [N = 48]	± SD/%
CSA of Tibial Nerve (mm^2)		
Mean ± SD	12.47 ± 3.45	–
Normal (<10.5)	22	45.83%
Enlarged (≥10.5)	26	54.17%
MTNF of Tibial Nerve (mm)		
Mean ± SD	5.67 ± 0.28	–
Normal (< 3)	20	41.67%
Enlarged (≥ 3)	28	58.33%
CSA of Common Peroneal Nerve (mm^2)		
Mean ± SD	10.47 ± 2.16	-
Normal (< 7.5)	28	58.33%
Enlarged (≥ 7.5)	20	41.67%
MTNF of Common Peroneal Nerve (mm)		
Mean ± SD	6.72 ± 0.86	-
Normal (<6)	24	50.00%
Enlarged (≥6)	24	50.00%

Table 7: Comparison of Sonographic Findings in Patients with and without Neuropathy

Characteristic	With Neuropathy (N = 28)	Without Neuropathy (N = 20)	*P- VALUE*
CSA of Tibial Nerve (mm^2)	16.56 ± 2.86	12.85 ± 2.75	t = 4.501 p < 0.001*
MTNF of Tibial Nerve (mm)	8.41 ± 0.11	7.05 ± 0.06	t = 50.123 p < 0.001*
CSA of Common Peroneal Nerve (mm^2)	11.46 ± 2.14	9.96 ± 1.21	t = 2.823 p < 0.001*
MTNF of Common Peroneal Nerve (mm)	7.25 ± 0.35	6.07 ± 0.26	t = 12.757 p < 0.001*

For the common peroneal nerve, the mean CSA was 10.47 mm^2 (SD ± 2.16). In this group, 58.33% had a normal CSA (<7.5 mm^2) and 41.67% have an enlarged CSA (≥7.5 mm^2). The mean MTNF for the common peroneal nerve was 6.72 mm (SD ± 0.86), with an equal distribution of patients having a normal MTNF (<6 mm) and an enlarged MTNF (≥6 mm), each constituting 50.00% of the cohort.

For the Tibial nerve:

- The mean cross-sectional area (CSA) in patients with neuropathy was 16.56 mm^2 (SD ± 2.86), significantly larger than the mean CSA of 12.85 mm^2 (SD ± 2.75) in patients without neuropathy (t = 4.501, p<0.001).
- The mean maximal thickness of the nerve fascicles (MTNF) in patients with neuropathy was 8.41 mm (SD ± 0.11), significantly larger than the mean MTNF of 7.05 mm (SD ± 0.06) in patients without neuropathy (t = 50.123, p < 0.001).

For the common peroneal nerve:

- The mean CSA in patients with neuropathy was 11.46 mm^2 (SD ± 2.14), significantly larger than the mean CSA of 9.96 mm^2 (SD ± 1.21) in patients without neuropathy (t = 2.823, p < 0.001).
- The mean MTNF in patients with neuropathy was 7.25 mm (SD ± 0.35), significantly larger than the mean MTNF of 6.07 mm (SD ± 0.26) in patients without neuropathy (t = 12.757, p<0.001).

Table 8: Correlation with Duration of Disease, Clinical features, Blood Sugar and HbA1c Levels.

Characteristic	CSA of Tibial Nerve (mm²)	MTNF of Tibial Nerve (mm)	CSA of Common Peroneal Nerve (mm²)	MTNF of Common Peroneal Nerve (mm)
Duration of Disease (years)				
r	0.65	0.62	0.57	0.53
p-value	<0.001*	<0.001*	<0.001*	<0.001*
Strength	Strong	Strong	Moderate	Moderate
Clinical features (Pain, Swelling. Numbness, Loss of sensation)				
r	0.54	0.64	0.48	0.42
p-value	<0.001*	<0.001*	<0.001*	<0.001*
Strength	Moderate	Moderate	Moderate	Moderate
Blood Sugar (mg/dL)				
r	0.53	0.50	0.49	0.45
p-value	<0.001*	*p* = 0.042*	*p* = 0.038*	*p* = 0.042*
Strength	Moderate	Moderate	Moderate	Moderate
HbA1c Levels (%)				
r	0.60	0.58	0.55	0.51
p-value	<0.001*	<0.001*	<0.001*	<0.001*
Strength	Strong	Moderate	Moderate	Moderate

The study's correlation analysis of sonographic findings and clinical parameters in patients with long-standing diabetes revealed several significant relationships. The duration of disease showed a strong positive correlation with CSA and MTNF of the Tibial nerve (r = 0.65 and r = 0.62, respectively; both $p < 0.001$) and a moderate positive correlation with CSA and MTNF of the common peroneal nerve (r = 0.57 and r = 0.53, respectively; both $P < 0.001$). Blood sugar levels are moderately correlated with all nerve parameters, showing the strongest correlation with the CSA of the Tibial nerve (r = 0.53, $P<0.001$) and the weakest with MTNF of the common peroneal nerve (r = 0.45, p = 0.042). HbA1c levels also demonstrated strong and moderate correlations with all parameters, with the highest correlation observed for the CSA of the Tibial nerve (r = 0.60, $p < 0.001$). Lastly, clinical features (pain, swelling, numbness and loss of sensation) were moderately correlated with all nerve measures, most notably with MTNF of the Tibial nerve (r = 0.64, $p < 0.001$) and least with MTNF of the common peroneal nerve (r = 0.42, $p < 0.001$).

Discussion

Diabetes is a common problem in the world affecting almost all organs. Diabetic peripheral neuropathy (DPN) is a distressing complication for patients with diabetes.[1] For nerve imaging, High-resolution ultrasound (HRU) is a relatively new technology. It's a quick, easy-to-use, affordable, and patient-friendly instrument that can quickly examine the entire nerve's course.[2, 3]

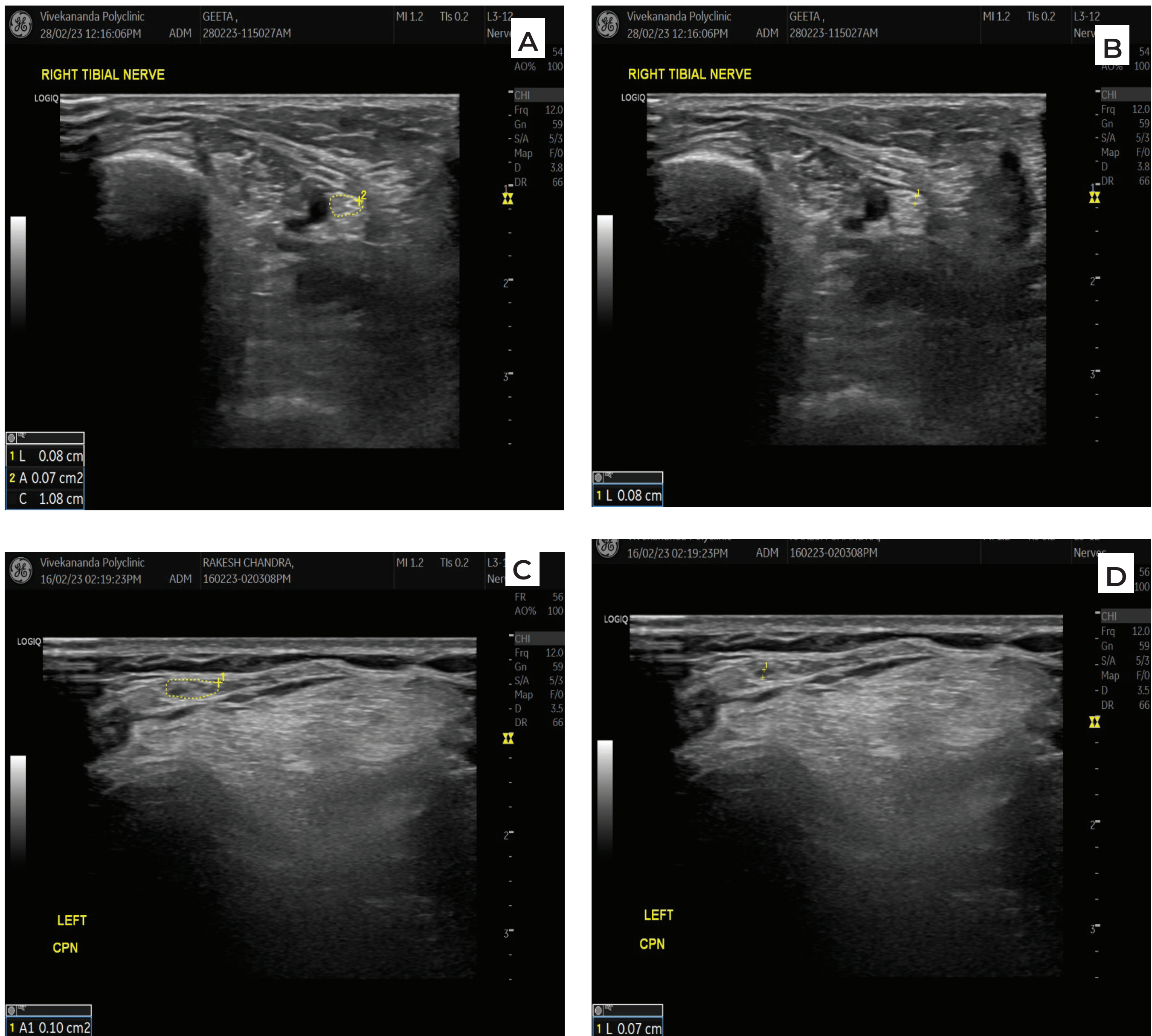

Figure 1: ***Case 1-*** A 45-years-old female patient diagnosed with Type-2 Diabetes Mellitus 10-years back. The patient did not have any neuropathic symptoms. Her HbA1c was 7.9% and RBS was 250 mg/dL. **A.** A transverse sonogram view of the tibial nerve at 3 cm proximal to Medial Malleolus (MM) showing normal Tibial nerve with Cross section area (CSA), measuring 7 mm^2. CSA was measured using a continuous trace method. **B.** Mean Thickness of Nerve Fascicle (MTNF) of tibial nerve was increased measuring 8 mm. **C.** A transverse sonogram view of Common Peroneal Nerve (CPN) at fibular neck level showing thickened nerve with CSA of 10 mm2. **D.** Mean Thickness of Nerve Fascicle (MTNF) of Common Peroneal Nerve (CPN) was increased measuring 7 mm.

Socio-demographic variables

The demographics of the patients in the current study showed the mean age of the patients was 47.78 years with a standard deviation (SD) of 6.63 years. The majority of patients were in age group between 50–60 years, followed by between 41–50 years and least in age group between 30–40 years. In the study majority were males 64% (*n* = 31). Male to female ratio was 1.8:1. Of the 48 patients with long-term diabetes in our study, 28 (58.33%) have been diagnosed with neuropathy, and 20 (41.67%) do not.

According to studies conducted by Narayan *et al.*,[5] the proportion of male patients with DPN was significantly higher (68%) than that of female patients. This mild chronic condition may prevent women from bringing them to the point of care because it

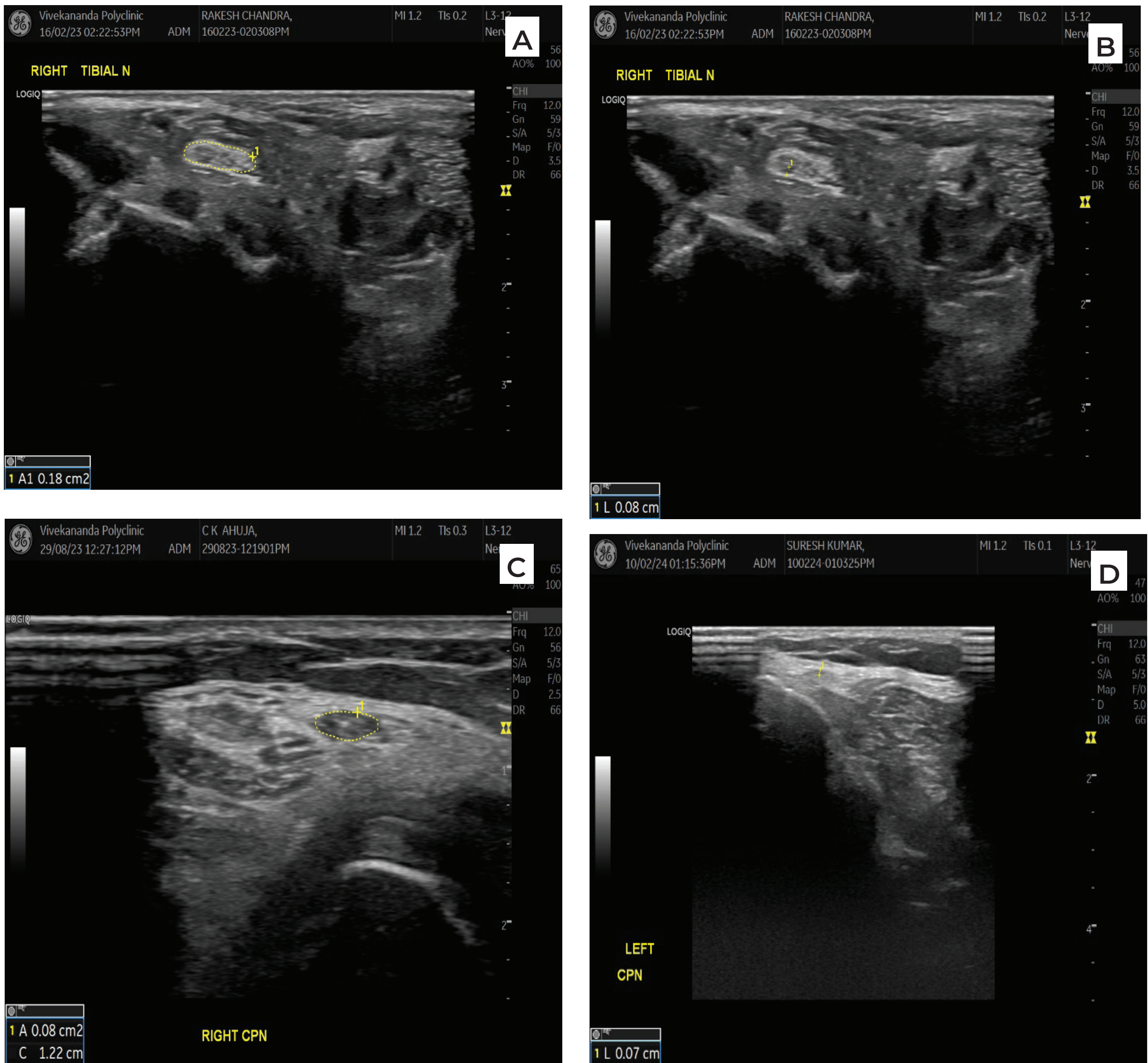

Figure 2: A 60-years-old female patient diagnosed with Type-2 Diabetes Mellitus 15-years back, presented with pain and numbness in both lower limbs. Her HbA1c was 8.5% and RBS was 255 mg/dL. **A.** A transverse sonogram view of the tibial nerve at 3 cm proximal to Medial Malleolus (MM) showing thickened tibial nerve with cross section area (CSA) measuring 18 mm^2. **B.** Mean Thickness of Nerve Fascicle (MTNF) of tibial nerve was increased measuring 8 mm. **C.** A transverse sonogram view of Common Peroneal Nerve (CPN) at fibular neck level showing thickened nerve with CSA of 8 mm^2. **D.** Mean Thickness of Nerve Fascicle (MTNF) of Common Peroneal Nerve (CPN) was normal measuring 4 mm.

necessitates frequent trips to tertiary care hospitals, particularly in rural areas of developing countries.[7,8]

The patients who were part of another study[9] ranged in age from 41 to 50 years. Just 4.76% of the population was older than 70-years. In the study, the proportion of male subjects (49.2%) and female subjects (50.8%) was nearly equal.

Clinical Characteristics

In this study, the mean duration of diabetes among the patients was 18.52 years (SD ± 5.65). Specifically, 56.25% have had diabetes for 10-15 years, 31.25% for 15.1-20 years, and 12.50% for more than 20 years. The duration of the disease showed a strong positive correlation with CSA

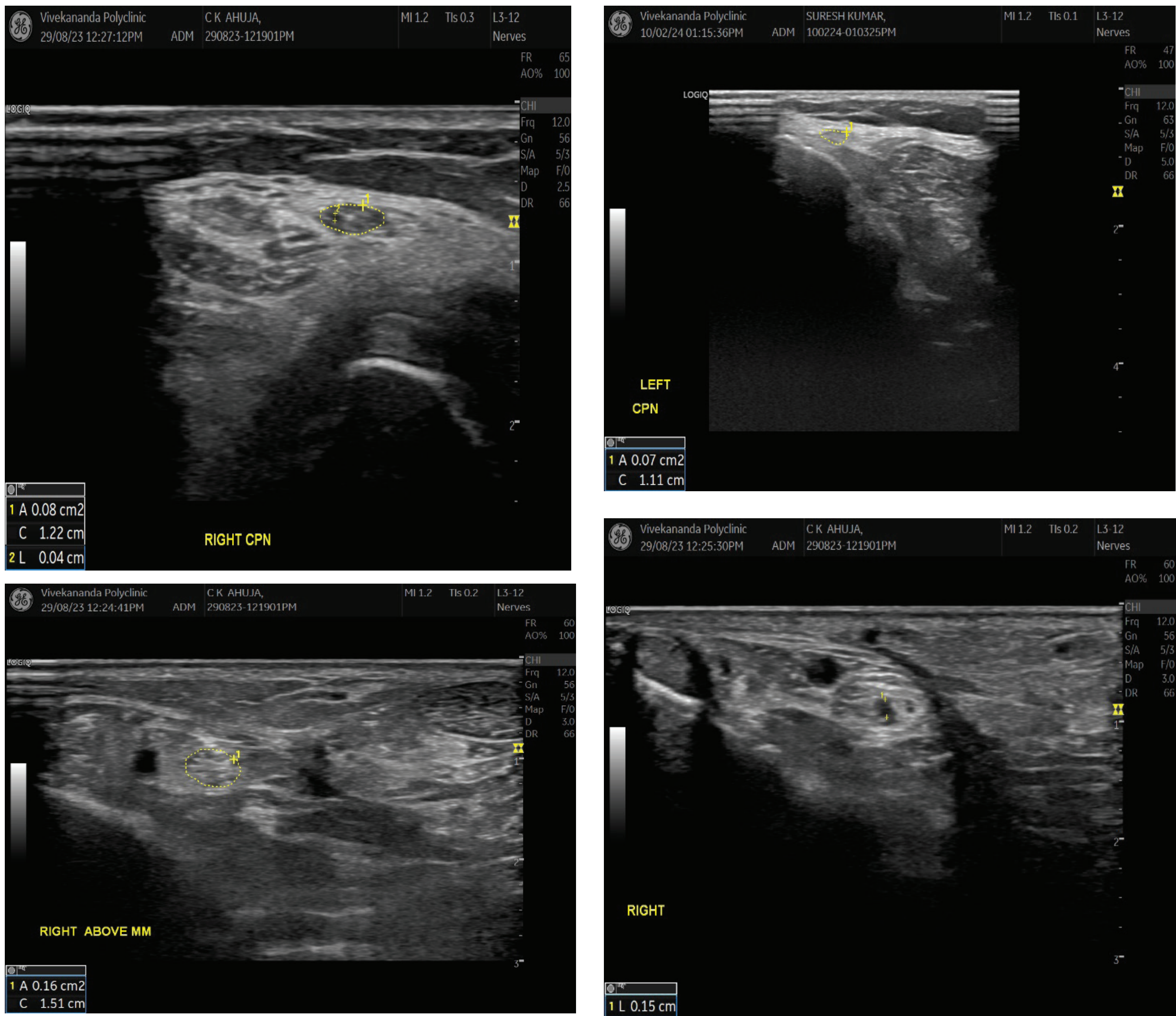

Figure 3: *Case 3*- A 56-years-old male patient diagnosed with Type-2 Diabetes Mellitus 14-years back, presented with pain and swelling in both lower limbs. His HbA1c was 9.8% and his RBS was 375 mg/dL. **A.** A transverse sonogram view of the tibial nerve at 3 cm proximal to Medial Malleolus (MM) showing thickened tibial nerve with Cross section area (CSA) measuring 16 mm^2. **B.** Mean Thickness of Nerve Fascicle (MTNF) of tibial nerve was increased measuring 15 mm. **C.** A transverse sonogram view of normal Common Peroneal Nerve (CPN) at fibular neck level with CSA of 7 mm^2. Mean Thickness of Nerve Fascicle (MTNF) of Common Peroneal Nerve (CPN) was increased measuring 7 mm.

and MTNF of the Tibial nerve and a moderate positive correlation with CSA and MTNF of the common peroneal nerve. In study conducted by Pirart *et al.*,[10] about 4400 diabetes patients underwent serial evaluations for 25-years. The length of diabetes was positively correlated with the onset of neuropathy, and by the time patients were 25-years-old, 50% of them had neuropathy. Although in study conducted by Narayan *et al.*[5], there was no statistically significant difference in the length of diabetes between patients with peripheral neuropathy and those without.

In this study, presenting Symptoms were pain, swelling, numbness, and loss of sensation. These clinical features were moderately correlated with all nerve measures, most notably with MTNF of the Tibial nerve and least with MTNF of the common peroneal nerve.

According to Callaghan BC *et al.*[11], Patients with DSP typically had numbness, tingling, pain,

and/or weakness that begin in the feet and spread proximally in a length-dependent fashion (stocking and glove distribution). The symptoms were symmetric with sensory symptoms more prominent than motor involvement.

Blood sugar and HbA1c levels

A long-term hyperglycemic state is the culprit for the occurrence of DPN. In the present study, patients with diabetes for an extended period of time have an average blood sugar level of 241.51 mg/dL (SD ± 76.84). A sizable fraction had poorly controlled blood glucose levels, as seen by the distribution, which places 45.83% between 150–250 mg/dL, 35.42% between 250 - 350 mg/dL, and 18.75% above 350 mg/dL.

HbA1c gives a good estimate of glycemic control for 3 months duration.

In the current investigation, individuals with chronic diabetes have an average HbA1c level of 8.21% (SD ± 1.32). HbA1c levels range from 6.25% below 7%, 54.17% between 7–8%, 20.83% between 8.1–9%, 16.67% between 9.1–10%, and 2.08% above 10%, according to the distribution. HbA1c levels demonstrated strong and moderate correlations with morphological parameters of nerves, with the highest correlation observed for the CSA of the Tibial nerve ($r = 0.60$, $p < 0.001$).

Kang *et al.*[12], found that HbA1c was significantly correlated with sural nerve CSA. Riazi *et al.*,[7] did not find any significant correlation between the nerve CSA and the values of HbA1c

In contrast, Singh *et al.*[13] studies revealed higher mean HbA1c levels and significant correlations between HbA1c levels and neuropathy severity and nerve conduction measures.

Sonographic Findings

In this study, the mean CSA of the Tibial nerve is 12.47 mm^2 (SD ± 3.45), and 54.17% of the patients have an enlarged CSA (≥ 10.5 mm^2). 5.67 mm (SD ± 0.28) is the mean MTNF, and 58.33% of patients have an enlarged MTNF (≥ 3 mm). On the other hand, the mean CSA of the common peroneal nerve is 10.47 mm^2 (SD ± 2.16), with 41.67% of cases showing an enlarged CSA (≥7.5 mm^2). Its MTNF is 6.72 mm (SD ± 0.86) on average, with an equal distribution of enlarged and normal MTNF.

Patients with neuropathy have a significantly higher mean CSA for the Tibial nerve (16.56 mm^2, SD ± 2.86) than patients without neuropathy (12.85 mm^2, SD ± 2.75; $t = 4.501$, $p<0.001$). Similarly, the mean MTNF in neuropathic patients is significantly higher than in non-neuropathic patients ($t = 50.123$, $p<0.001$), measuring 8.41 mm (SD ± 0.11) as opposed to 7.05 mm (SD ± 0.06). Neuropathic patients also show a significantly larger mean CSA of 11.46 mm^2 (SD ± 2.14) for the common peroneal nerve in comparison to 9.96 mm^2 (SD ± 1.21) for non-neuropathic patients ($t = 2.823$, $p < 0.001$). Furthermore, the mean MTNF in patients with neuropathic patients is significantly higher (7.25 mm, SD ± 0.35) than in patients without neuropathy (6.07 mm, SD ± 0.26) ($t = 12.757$, $p<0.001$).

Shamrendra N, *et al.*[5] Conducted a study which demonstrated increased CSA of peripheral nerves (Median nerve - 7.58 mm^2 with delta value 1.87 mm^2, ulnar nerve - 5.83 mm^2 with a delta value of 1.52 mm^2, common peroneal nerve - 10.23 mm^2 with a delta value of 1.65 mm^2, Tibial nerve - 13.12 mm^2 with a delta value of 1.95 mm^2) as compared to non-neuropathic patients in similar settings ($p < 0.05$).

In this study, the mean MTNF (maximum thickness of nerve fascicle) for the Tibial nerve in neuropathic patients is significantly higher than in non-neuropathic patients ($t = 50.123$, $p < 0.001$). The MTNF may be therefore considered an indicator of the level of nerve fascicle swelling.[5]

This study confirms significant differences in nerve morphology between diabetic patients with and without neuropathy and emphasizes the need for customized treatment plans based on changes specific to individual nerves.

Correlation between nerve morphology and indicators of diabetic neuropathy

As compared to Sundaram *et al.*[15] and Ranjan *et al.*[9] the current study validates robust relationships between nerve morphology and indicators of diabetic neuropathy. The duration of disease showed a strong positive correlation with CSA and MTNF of the Tibial nerve ($r = 0.65$ and $r = 0.62$, respectively; both $p < 0.001$) and a moderate positive correlation with CSA and MTNF of the common peroneal nerve ($r = 0.57$ and $r = 0.53$, respectively;

both $P < 0.001$). Blood sugar levels are moderately correlated with all nerve parameters, showing the strongest correlation with the CSA of the Tibial nerve ($r = 0.53$, $p < 0.001$) and the weakest with MTNF of the common peroneal nerve ($r = 0.45$, $p = 0.042$). HbA1c levels also demonstrated strong and moderate correlations with all parameters, with the highest correlation observed for the CSA of the Tibial nerve ($r = 0.60$, $p < 0.001$). Lastly, clinical features (pain, swelling, numbness, loss of sensation) were moderately correlated with all nerve measures, most notably with MTNF of the Tibial nerve ($r = 0.64$, $p < 0.001$) and least with MTNF of the common peroneal nerve ($r = 0.42$, $p < 0.001$).

These perspectives are extremely helpful to clinicians in evaluating and treating diabetic neuropathy, highlighting the significance of early identification and close observation to prevent additional nerve damage and enhance patient outcomes.

Conclusion

the study highlights the significant impact of long-standing diabetes on the Tibial and common peroneal nerves, underscoring the importance of sonographic evaluation in diabetic patients. The findings demonstrate that patients with longer durations of diabetes and higher blood sugar and HbA1c levels tend to have more pronounced sonographic abnormalities, including enlarged cross-sectional areas (CSA) and maximal thickness of nerve fascicles (MTNF). The correlation between clinical features such as pain, swelling, numbness, and loss of sensation with sonographic abnormalities further emphasizes the clinical relevance of these measurements. By identifying these changes early, healthcare providers can implement more targeted interventions to mitigate the progression of neuropathy and improve the quality of life for diabetic patients.

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