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Foot screening and customized health education program for patients with diabetic peripheral neuropathy: A nurse-led, real-world observational study

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ABSTRACT

Background: Research has shown that DPN affects 50 % of individuals with diabetes and, in severe cases, can lead to amputation or death. Interventions led by doctors for DPN have demonstrated limited effectiveness in delaying its onset and progression. Nevertheless, there is an increasing recognition of the significance of nurse-led screening and health education in the early detection and slowing down of DPN.

Method: The present study conducted a retrospective analysis of medical records of 10,191 diabetic patients from 2019 to 2023, who also regularly attended outpatient clinics. Patients with incomplete medical data, transfers, critical conditions or death, existing foot ulcers or amputations, bedridden or uncooperative individuals (5,470 individuals) were excluded, and a total of 4,721 individuals were selected for analysis. The screening and intervention components of the FSCHE program were all led by nurses. A total of 2022 participants received foot screening and customized health education (FSCHE) program, while 2699 participants recevied regular care. The primary outcome is on determining the prevalence rate of DPN among all the included diabetic patients. The data was collected through experimental tests and nurse-led foot screening. Prevalence rates were reported as the number of cases per 1000 individuals. Odds Ratios were calculated to approximate Risk Ratios to determine the effectiveness of the FSCHE program.

Results: The prevalence of DPN in diabetic patients who received the FSCHE program decreased from 557 cases per 1000 individuals in 2019 to 199 cases per 1000 individuals in 2023. The hospitalization duration decreased from 11.2 days to 7.59 days. The risk of DPN in diabetic patients participating in the FSCHE program was 0.741 times higher than that of regular diabetes care (RR [95 % CI]: 0.741 [0.654, 0.840], $p < 0.001$). The DPN-related risk factors showed promising control results as well.

Conclusions: In this observational study conducted among Chinese patients with diabetes, it was found that the nurse-led FSCHE program effectively manages DPN and its associated risk factors. These results highlight the importance of employing objective screening tools to detect DPN at an

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early stage, as well as the significance of nurse-led interventions in promoting healthy behaviors and preventing the development and progression of DPN.

1. Introduction

Diabetic peripheral neuropathy (DPN) is one of the most important diabetic complications which significantly increased the risk of diabetic foot, potential amputations cardiovascular mortality, and renal impairment (Boulton et al., 2018; Singh et al., 2005). It is well-established that DPN is a consequence of long-term hyperglycemia, metabolic disorders, and cardiovascular risk factors (Franceschi et al., 2022). Furthermore, DPN worsens and progresses as the duration of diabetes increases (Yoo et al., 2015). Approximately half of all diabetes patients will develop DPN. However, the actual prevalence may be underestimated, because in the early stage of DPN, diabetic neuropathy is often asymptomatic (Hicks and Selvin, 2019; Sepat and Wasnik, 2020). In DPN, small nerve fibers are initially affected, often without symptoms, preceding the impairment of larger nerve fibers (Quattrini et al., 2007; Umapathi et al., 2007). By the time common DPN symptoms such as pain, numbness, and abnormal sensations appear, significant damage has already occurred to the larger nerve fibers (Elafros et al., 2022). Previous studies have shown that early detection and effective management of DPN risk factors can reduce its prevalence or potentially alter its natural progression (Hicks and Selvin, 2019). Therefore, early detection and intervention for DPN are of utmost importance.

Numerous studies have demonstrated the significance of employing neuroelectrophysiological tests and skin biopsies for early clinical screening and diagnosis of DPN. However, these tests are time-consuming, invasive, and have limited extrapolation capabilities (Allen et al., 2016; Peltier et al., 2014; Pop-Busui et al., 2017). Consequently, the absence of a straightforward indicator for early detection of DPN remains a challenge in routine clinical practice (Selvarajah et al., 2019). Clinicians commonly employ a blend of neurologic rating scales and physical examinations, including the Michigan Neuropathy Screening Instrument and Semmes-Weinstein monofilament, to assess DPN in diabetic patients (Herman et al., 2012). Additionally, certain DPN screening devices, such as the VSA-3000 vibration sense analyzer, are utilized in both outpatient and inpatient settings, exhibiting commendable diagnostic efficacy for large fiber neuropathy (Santos et al., 2018). However, numerous studies have demonstrated the subjective nature of these screening methods and their inclination to diagnose DPN only after the manifestation of irreversible nerve damage (Coppini, 2020; Yorek et al., 2018). Furthermore, the classification of DPN includes large fiber neuropathy, small fiber neuropathy, and mixed-type lesions, thereby posing a considerable challenge to conducting a comprehensive screening and diagnosis with a single examination (Sepat and Wasnik, 2020). As a result, combination of different methods to screen DPN has been proposed by clinics and turned to be effective (Binns-Hall et al., 2018). A series of screening methods with high levels of accuracy may fulfill the screening requirements of DPN. SUDOSCAN, which utilizes electrochemical skin conductance (ESC) values, is a noninvasive and convenient tool for assessing the functionality of unmyelinated C-fibers that innervate sweat glands (Mao et al., 2017). These ESC values can quantitatively measure sudomotor function and serve as a surrogate marker for early DPN (Mao et al., 2017). Vibration perception threshold (VPT) reflects the condition of large sensory fiber nerve pathways and is highly effective and specific in diagnosing DPN (Santos et al., 2018; Wang et al., 2020). Additionally, the ankle-brachial index (ABI) has been proved to be associated with both DPN and diabetic foot (Aragón-Sánchez and Lázaro-Martínez, 2013). Hence, the integrating of these methods may have promising effects.

Intervention is of equal importance to screening in the management of DPN. The occurrence of DPN is strongly associated with prolonged hyperglycemia (Franceschi et al., 2022), the course of diabetes (Yoo et al., 2015), metabolic abnormalities (Pop-Busui et al., 2022), advanced age (Franceschi et al., 2022), hypertension (Franceschi et al., 2022), obesity (Li et al., 2015), and an unhealthy lifestyle (Christensen et al., 2020). Although early intervention has shown promise in managing these factors, the occurrence and progression of DPN continue to develop despite proactive medication interventions provided by healthcare professionals in clinical settings (Elafros et al., 2022; Selvarajah et al., 2019). As a result, involvement of nurses in health education plays a crucial role in preventing DPN and its complications. Many studies have demonstrated that lifestyle interventions and structured health education can reduce the occurrence and severity of DPN (Ghavami et al., 2018; Lincoln et al., 2008; Selvarajah et al., 2019). However, several recent large intervention studies targeting multiple risk factors have not shown a reduction in DPN (Selvarajah et al., 2019), possibly because of late detection or deficient sensitivity and reliability in diagnosing or quantifying DPN (Ponirakis et al., 2019).

Hence, our research team integrated screening methods and health education to develop a nurse-led foot screening and customized health education (FSCHE) program. This program incorporates comprehensive foot screening utilizing precise devices, including VPT, ESC, and ABI. This screening mode consists of the evaluation of small nerve fibers, large nerve fibers, and peripheral vascular disease, and can quickly obtain DPN screening results within 30 minutes in a noninvasive manner. We also implemented a standardized health education program to efficiently prevent and manage DPN. In this study, we performed a retrospective real-world analysis of medical records from 2019 to 2023 to examine the prevalence rate of DPN and its associated risk factors and to evaluate the effectiveness of the FSCHE program. This study also analyzed the impairments related to DPN at different risk levels.

2. Method

2.1. Study design and sample

This real-world observational study utilized medical record data from the Division of Endocrine and Metabolic Diseases of the Third Affiliated Hospital of Sun Yat-sen University, Guangzhou, Guangdong Province, China. The dataset included all patients with type 2

diabetes and those with type 1 diabetes of more than five years' duration who were admitted to our division and regularly visited our outpatient department between 2019 and 2023, with a population size of 4721. Among them, 2202 individuals who were able to receive regular foot screening and customized health education participate in the FSCHE program administered by nurses (Ran et al., 2019), while the other 2699 individuals receive regular diabetes care (***Supplementary material 1***). This study was approved by the Ethics Committee of the Third Affiliated Hospital of Sun Yat-sen University (ID: II2023–315–01) and followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for cohort studies (von Elm et al., 2008). This study was prospectively registered in the Chinese Clinical Trial Registry (ID: ChiCTR2200060894).

2.2. Inclusion and exclusion criteria for retrospective data

The inclusion criteria were as follows: (1) patients diagnosed with type 2 diabetes and those with type 1 diabetes of more than five years' duration (ICD-10-CM: E10, E11), (2) aged 18 years or above, and (3) able to communicate effectively in Mandarin or Cantonese. The exclusion criteria were as follows: (1) incomplete or inaccurate medical records; (2) patients transferred to a different division, critically ill, or deceased during their hospitalization; (3) patients with foot ulcers or amputations due to diabetes; and (4) patients who were bedridden or unable to stand and cooperate with the examination.

2.3. Measures

2.3.1. Diabetic peripheral neuropathy (DPN) identification

The diagnosis of DPN was based on the International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM) codes (***Supplementary material 2: eTable 1***) (Centers for Medicare & Medicaid Services, n.d.). Patients who presented with a combination of symptoms and signs of neuropathy, including at least two or more of the followings: neuropathic symptoms, decreased distal sensation, or unequivocally decreased or absent ankle reflexes, were identified as cases of DPN (i.e., DPN-positive) (Tesfaye et al., 2010). The diagnostic coding of DPN was previously validated by endocrine physicians who reviewed the clinical and laboratory evaluations. Patients with missing information were excluded from the analysis to ensure data consistency and to maintain high data quality.

2.3.2. Clinical and laboratory evaluations

Demographic data collected from medical records included age, sex, place of residence, body mass index (BMI), and lifestyle factors such as alcohol and tobacco use. In-hospital examinations, as documented in the medical records during the late inpatient period, were performed exclusively at the Third Affiliated Hospital of Sun Yat-sen University and included complete blood count, blood biochemistry, cardiac color Doppler ultrasound, and carotid artery color Doppler ultrasound (***Supplementary material 2: eTable 2***). The patient identity information will be treated with utmost confidentiality.

2.3.3. Regular diabetes care

Every patient with diabetes received regular diabetes care at our division's in-hospital departments. These included regular monitoring of blood glucose levels, guidance on medication use, and assistance with skincare routines, among other services. For more specific information, please refer to ***Supplementary material 1***.

2.3.4. Foot screening and customized health education (FSCHE) program

Patients participated in the FSCHE program should undergo foot screening regularly. During the foot screening conducted as part of the FSCHE program, diabetes patients who tested positive for one or more indicators (such as Ankle-Brachial Index (ABI) < 0.9 or ABI > 1.3, Vibration Perception Threshold (VPT) ≥ 15 Volts, or Electronic Skin Conductivity (ESC) < 60 μSiemens) are classified as being at a high risk for DPN (i.e. DPN-high risk) (Hinchliffe et al., 2020; Liu et al., 2021; Vinik et al., 2015). This screening process involved the utilization of advanced medical equipment and tests. ***(Supplementary material 2: eTable 3***). Based on the foot screening results, nurses will provide tailored health education as well as regular diabetes care. Different interventions are offered to high-risk and low-risk groups (***Supplementary material 1***). In the FSCHE program, various DPN-related factors were examined to evaluate its effectiveness, including the neutrophil-to-lymphocyte ratio, glycosylated hemoglobin levels, ejection fraction, glomerular filtration rate, low-density lipoprotein and high-density lipoprotein levels, triglyceride levels, total cholesterol levels, and the presence of carotid artery plaques.

2.4. Outcomes

In our study, the primary outcome was the prevalence rate of DPN among all included patients with diabetes. The secondary outcome is the length of hospital stay.

2.5. Statistical analysis

Statistical analyses were performed using the Python 3.9 and R 4.4.1. All tests were two-sided, and statistical significance was determined using a p-value of <0.05. Categorical data were presented as frequencies and percentages, whereas continuous data were expressed as means and standard deviations. Prevalence rates were reported as the number of cases per 1000 individuals. We

conducted ordinary least squares to calculate the slope of changes in DPN prevalence rates and hospital stay length over investigated time (year 2019 to 2023). This analysis aimed to compare the effectiveness of the FSCHE group with the regular care group in DPN prevention and care.

Descriptive statistics were used to examine the cohort, focusing specifically on the demographic characteristics and risk factors associated with DPN from 2019 to 2023. Odds Ratios were calculated to approximate Risk Ratios as well as their corresponding 95 % confidence intervals (CIs) in the case-control part to determine the effectiveness of the FSCHE program in DPN protection (Cummings, 2009). Differences in characteristics and risk factors among patients with diabetes from 2019 to 2023 were assessed using the Pearson Chi-square Test and One-way ANOVA. An independent *t*-test was used to identify the disparities in DPN-related risk factors between the FSCHE program group and the regular diabetes care group among all included patients. The Mann-Whitney U test and independent *t*-test were conducted to examine the differences in disease outcomes between the DPN-high-risk and DPN-low-risk groups within the FSCHE program.

In this study, to better understand the significance of the FSCHE program's screening indicators for DPN patients, we conducted logistic regression analyses using the occurrence of DPN (yes or no, binary) as the dependent variable, and ABI, VPT, and ESC as the independent variables. The model was adjusted for demographic information and disease-related data of the analyzed population, including age, sex, region, BMI, neutrophil-to-lymphocyte ratio, glycosylated hemoglobin levels, ejection fraction, glomerular filtration rate, low-density lipoprotein and high-density lipoprotein levels, triglyceride levels, total cholesterol levels, and the presence of carotid artery plaques, and length of hospital stay.

3. Results

A total of 10,191 patients were identified between January 1, 2019, and August 15, 2023. Among them, 3909 patients with incomplete BMI and lifestyle records and 1565 patients with missing laboratory examination information due to age were excluded from the analysis (***Supplementary material 2: eFigure 1***), resulting in a final sample size of 4721 patients for the main analysis. Of these, 1403 were diagnosed with DPN. In addition, a total of 2202 patients participated in the FSCHE program while the other 2699 patients receive regular diabetes care (Supplementary material 2: eFigure 1). Detailed characteristics information of the included patients from 2019 to 2023 can be found in Table 1.

Table 1
Characteristics of patients with diabetes in 2019–2023.

Characteristic	Participants, N (%)						
	All participants (N=4721)	2019 year (N=128)	2020 year (N=260)	2021 year (N=1578)	2022 year (N=1699)	2023 year (N=1056)	*P* value [b]
Age (mean ± SD)	57.23 ± 14.91	60.6 ± 12.60	58.47 ± 14.36	56.80 ± 14.99	57.26 ± 14.99	57.10 ± 15.00	0.044
Sex							
Female	1983 (42.0)	60 (46.9)	108 (41.5)	651 (41.3)	697 (41.0)	467 (44.2)	0.350
Male	2738 (58.0)	68 (53.1)	152 (58.5)	927 (58.7)	1002 (59.0)	589 (55.8)	
Region [a]							
Central China	607 (12.9)	18 (14.1)	31 (11.9)	203 (12.9)	218 (12.8)	137 (13.0)	0.207
East China	364 (7.7)	11 (8.6)	19 (7.3)	110 (7.0)	152 (8.9)	72 (6.8)	
North China	61 (1.3)	1 (0.8)	3 (1.2)	20 (3.0)	24 (1.4)	13 (1.2)	
South China	3341 (70.8)	87 (68.0)	187 (71.9)	1137 (72.1)	1174 (69.1)	756 (71.6)	
Northeast China	134 (2.8)	2 (1.6)	8 (3.1)	48 (3.0)	53 (3.1)	23 (2.2)	
Northwest China	75 (16)	4 (3.1)	3 (1.2)	20 (1.3)	25 (1.5)	23 (2.2)	
Southwest China	139 (2.9)	5 (3.9)	9 (3.5)	40 (2.5)	53 (3.1)	32 (3.0)	
BMI (mean ± SD)	24.03 ± 3.82	23.92 ± 3.25	34.35 ± 3.77	24.00 ± 3.86	24.02 ± 3.84	24.08 ± 3.81	0.704
Smoking							
Yes	957 (20.3)	19 (14.8)	55 (21.2)	309 (19.6)	348 (20.5)	226 (21.4)	0.433
No	3764 (79.7)	109 (85.2)	205 (78.8)	1269 (80.4)	1351 (79.5)	830 (78.6)	
Alcohol consuming							
Yes	664 (14.1)	15 (11.7)	41 (15.8)	214 (13.6)	247 (14.5)	147 (13.9)	0.760
No	4057 (85.9)	113 (88.3)	219 (84.2)	1364 (86.4)	1452 (85.5)	909 (86.1)	
Duration of hospitalization (mean ± SD)	9.27 ± 4.61	11.30 ± 3.60	11.40 ± 5.27	10.00 ± 4.69	8.93 ± 4.88	7.94 ± 3.36	<0.001
Diagnosed as diabetic peripheral neuropathy							
Yes	1403 (29.7)	64 (50.0)	123 (47.3)	622 (39.4)	414 (24.4)	180 (17.0)	<0.001
No	3318 (70.3)	64 (50.0)	137 (52.7)	956 (60.6)	1285 (75.6)	876 (83.0)	

Note:.

[a] The areas are defined by Chinese government refer to the Brief Book of Administrative Divisions of Villages and Towns in People's Republic of China (PRC). Each area contains several provinces/ autonomous regions/ municipalities/ Special Administrative Regions.

[b] The *P* value indicates whether there are differences in the characteristics of the survey subjects from 2019 to 2023. In the case of categorical variables, we employed the chi-square test to examine the overall disparities among various patient categories across different years. We also utilized one-way ANOVA to investigate the overall variances of continuous variables across different years.

3.1. The general effects of FSCHE program

In the FSCHE program group, the prevalence of DPN among patients with diabetes decreased from 557 cases per 1000 individuals in 2019 to 199 cases per 1000 individuals in 2023. The precision of integrated screening in our study was 0.625. In addition, when compared to the regular care group, the FSCHE group showed a similar decreasing trend and had shorter hospitalization duration (with a decrease from 11.2 days to 7.59 days) (Fig. 1). Regarding the rate of decrease, the FSCHE program demonstrated a faster decline compared to the regular care group, as indicated by the slopes analyzed using ordinary least squares. Specifically, the FSCHE group showed a greater reduction in DPN prevalence (−0.322 vs. −0.157, $p < 0.001$) and length of hospital stay (−0.239 vs. −0.199, $p < 0.001$) than the regular care group. Furthermore, diabetic patients participating in the FSCHE program had a disease onset risk for DPN that was 0.741 times of that of those in regular care (RR [95 % CI]: 0.741 [0.654, 0.840], $p < 0.001$).

3.2. Effects of FSCHE program in risk factors associated with DPN

In terms of risk factors associated with DPN, the provision of regular diabetes care by nurses has been found to play a significant role in managing various factors such as the neutrophil-to-lymphocyte ratio, glycosylated hemoglobin, low-density lipoprotein, and total cholesterol levels. Moreover, the FSCHE program had a more favorable impact on managing the neutrophil-to-lymphocyte ratio and glomerular filtration rate than regular diabetes care alone (Table 2).

3.3. Effects of FSCHE program in different risk groups

The FSCHE program showed good attendance rates (Table 3), except in 2019 and 2020 when implementation was limited due to the COVID pandemic. Among different risk groups, there was a significant decrease in the prevalence rates of DPN cases and the length of hospital stay, as detailed in Table 3. Therefore, we also compared the differences in disease outcomes among risk groups (***Supplementary material 2: eTable 4***). To assess future renal function impairment using data from the FSCHE program, a prediction model was also developed (***Supplementary material 2: eTable 5 and eFigure 2***).

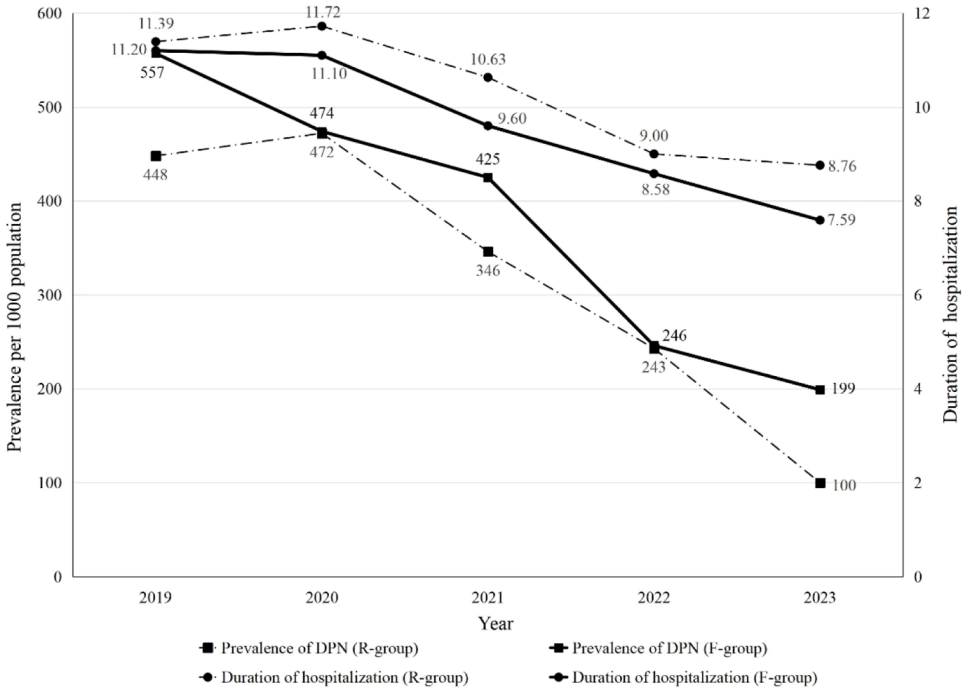

Fig. 1. Prevalence of DPN and duration of hospitalization among diabetes patients in FSCHE program, 2019–2023.
This graph illustrates line charts that depict the prevalence of diabetic peripheral neuropathy (DPN) and hospitalization days for the Regular Care Group and the FSCHE Program Group from 2019 to 2023. The occurrence of DPN is measured by the number of DPN cases per 1000 diabetic patients. The solid line represents the FSCHE Program Group, while the dashed line represents the Regular Care Group.
From the graph, it is evident that the prevalence of DPN among high DPN-risk patients entering the FSCHE Program Group is gradually approaching that of the low DPN-risk population in the Regular Care Group. Both groups exhibit an overall decreasing trend in DPN prevalence. Additionally, the FSCHE Program Group demonstrates shorter hospitalization days compared to the Regular Care Group.

Table 2
Investigated risk factors among diabetes patients in 2019–2023.

		Mean ± SD		
Risk factors	Years	Patients received FSCHE program (N = 2202)	Patients received regular diabetes care (N = 2519)	*P* value [c]
Neutrophil-lymphocyte ratio	Pooled	2.25 ± 1.66	2.66 ± 2.99	<0.001
	2019	2.28 ± 1.59	2.28 ± 1.80	0.992
	2020	2.55 ± 2.49	2.24 ± 1.44	0.216
	2021	2.20 ± 1.35	2.69 ± 2.83	<0.001
	2022	2.34 ± 2.10	2.60 ± 2.59	0.067
	2023	2.23 ± 1.62	3.15 ± 0.28	<0.001
		P value [a]	*P* value [b]	
Glycosylated hemoglobin		0.175	0.014	
	Pooled	8.73 ± 2.31	8.75 ± 2.40	0.854
	2019	8.01 ± 1.93	8.51 ± 1.94	0.144
	2020	8.57 ± 2.13	9.03 ± 2.48	0.105
	2021	8.83 ± 1.35	8.72 ± 2.43	0.397
	2022	8.20 ± 2.10	8.71 ± 2.44	0.001
	2023	8.92 ± 2.35	8.88 ± 2.19	0.781
		P value [a]	*P* value [b]	
Ejection fraction		<0.001	0.445	
	Pooled	66.92 ± 5.62	67.16 ± 5.28	0.131
	2019	65.95 ± 6.79	66.93 ± 4.70	0.351
	2020	67.02 ± 4.30	66.88 ± 4.88	0.816
	2021	66.59 ± 5.41	66.72 ± 5.56	0.644
	2022	67.10 ± 5.99	67.35 ± 5.20	0.495
	2023	67.34 ± 5.81	67.35 ± 5.35	0.984
		P value [a]	*P* value [b]	
Glomerular filtration rate		0.048	0.135	
	Pooled	95.31 ± 29.71	93.65 ± 32.60	0.068
	2019	94.47 ± 25.05	89.27 ± 32.61	0.317
	2020	91.53 ± 30.72	90.93 ± 30.09	0.874
	2021	96.00 ± 27.60	92.06 ± 34.84	0.013
	2022	95.10 ± 28.85	95.06 ± 31.51	0.982
	2023	95.26 ± 32.71	92.51 ± 33.65	0.223
		P value [a]	*P* value [b]	
Low-density lipoprotein		0.604	0.163	
	Pooled	2.82 ± 1.07	2.85 ± 1.18	0.373
	2019	2.39 ± 0.84	2.59 ± 1.73	0.430
	2020	2.59 ± 1.01	2.61 ± 0.97	0.851
	2021	2.78 ± 1.06	2.74 ± 1.05	0.511
	2022	2.68 ± 1.08	2.95 ± 1.20	0.001
	2023	3.01 ± 1.09	2.93 ± 0.07	0.305
		P value [a]	*P* value [b]	
High-density lipoprotein		<0.001	0.001	
	Pooled	1.05 ± 0.31	1.02 ± 0.30	0.002
	2019	1.08 ± 0.32	1.05 ± 0.31	0.547
	2020	1.04 ± 0.29	1.05 ± 0.31	0.675
	2021	1.02 ± 0.30	2.74 ± 1.05	0.371
	2022	1.07 ± 0.35	1.02 ± 0.30	0.006
	2023	1.06 ± 0.31	1.00 ± 0.31	0.006
		P value [a]	*P* value	
Triglyceride		0.053	0.468	
	Pooled	1.97 ± 2.21	2.13 ± 3.32	0.066
	2019	1.98 ± 2.96	2.32 ± 3.97	0.577
	2020	1.91 ± 1.68	2.01 ± 3.35	0.760
	2021	1.99 ± 2.20	1.96 ± 2.08	0.812
	2022	1.83 ± 1.75	2.16 ± 3.48	0.019
	2023	2.02 ± 2.39	2.31 ± 4.31	0.254
		P value [a]	*P* value [b]	
Total cholesterol		0.798	0.568	
	Pooled	4.76 ± 1.39	4.84 ± 1.60	0.088
	2019	4.37 ± 1.43	4.67 ± 1.89	0.302

(*continued on next page*)

Table 2 (*continued*)

		P value [a]	*P* value [b]	
	2020	4.49 ± 1.29	4.60 ± 1.51	0.530
	2021	4.78 ± 1.39	1.96 ± 2.08	0.487
	2022	4.59 ± 1.43	4.93 ± 1.67	<0.001
	2023	4.90 ± 1.38	4.77 ± 1.68	0.254
		P value [a]	*P* value [b]	
		<0.001	0.019	
	Pooled	934 (42.4) / 1268 (57.6)	1069 (42.4) / 1450 (57.6)	0.506
Carotid artery plaque	2019	28 (41.8) / 39 (58.2)	40 (65.6) / 21 (34.4)	0.392
Yes. N (%) / No. N (%)	2020	43 (33.9) / 84 (66.1)	73 (54.9) / 60 (45.1)	0.064
	2021	249 (40.3) / 369 (59.7)	564 (58.8) / 396 (41.2)	0.705
	2022	600 (42.9) / 798 (57.1)	172 (57.1) / 129 (42.9)	0.984
	2023	149 (48.2) / 160 (51.8)	419 (56.1) / 328 (43.9)	0.200
		P value [a]	*P* value [b]	
		0.520	0.053	

Note:.

[a] The *P* value indicates the differences among the investigated years for each risk factor in the FSCHE program group. For categorical variables, we employed Chi-square analysis. For continuous variables, we utilized ONE-WAY ANOVA for analysis.

[b] The *P* value indicates the differences among the investigated years for each risk factor in the regular diabetes care group. For categorical variables, we employed Chi-square analysis. For continuous variables, we utilized ONE-WAY ANOVA for analysis.

[c] This *P* value demonstrates the differences between the FSCHE program group and the regular diabetes care group for both pooled data and individual year's data, using an independent *t*-test.

3.4. Associations between ABI, VPT, ESC, and the occurrence of DPN

After adjusting for demographic and disease information from the FSCHE program data, we used logistic regression to analyze the relationship between foot screening indicators (ABI, VPT, ESC) and the occurrence of DPN (Fig. 2). The results indicated that both hand ESC (OR [95 % CI]: 0.980 [0.973–0.987], $p < 0.001$) and foot ESC (OR [95 % CI]: 1.007 [1.0001–1.014], $p < 0.047$) are significantly associated with the occurrence of DPN.

4. Discussion

This real-world observational study reported decreasing trends in the prevalence of DPN and duration of hospitalization among patients with diabetes from 2019 to 2023. The FSCHE program in our study included nurse-led early foot screening to identify high-risk DPN patients and timely targeted health education, which showed significant effects in reducing the prevalence of DPN and shortening hospitalization duration in patients with diabetes. The results of the current study highlight the significance of nurse involvement in DPN management, as well as the effective implementation of integrated screening models and health education programs for early detection and intervention in a large population with diabetes. The findings of the present study provide evidence supporting the effectiveness of integrated screening models of DPN, as well as the favorable influence associated with the implementation of the FSCHE program.

Effective management of DPN depends on the identification of significant risk factors and early screening through comprehensive diagnosis (Laxmi and Prabhakar, 2023). However, in the early stages, up to 50 % of DPN patients are asymptomatic (Pop-Busui et al., 2017). As a result, the current emphasis in the field of health is on early screening and intervention for DPN (Tavakoli et al., 2023). In our study, we incorporated SUDOSCAN screening, an indicator for early detection of DPN, which distinguishes it from previous studies (Mao et al., 2017). As a result, we can identify and intervene DPN at an earlier stage. The combined screening mode of the FSCHE program exhibited specificity in large populations, which is comparable to the results of previous studies. This study, along with previous research, demonstrates the high precision of quantitative indicators, including VPT, ESC, and ABI, in the early detection of DPN (Binns-Hall et al., 2018; Chevtchouk et al., 2017; Lin et al., 2022; Liu et al., 2021; Martin et al., 2010). Previous studies have not incorporated the three commonly used screening indicators for DPN screening. Upon integrating these indicators into the screening process, a robust improvement in screening efficiency was observed. The precision values obtained in this study (0.625) are consistent with the range reported in previous studies (0.320 to 0.861) (Selvarajah et al., 2019). Moreover, compared to previous studies, the FSCHE program demonstrated a protective effect of preventing and slowing down the occurrence and progression of DPN (RR [95 % CI]: 0.741), indicating that it is a pioneering screening intervention program effectively addressing DPN in a large population (Selvarajah et al., 2019).

Previous studies have found that doctor-led intensive glucose-lowering treatment and symptomatic treatment cannot effectively control the progression of DPN (Ziegler et al., 2022). Therefore, studies have redirected their attention towards nurse-led lifestyle interventions, shifting the emphasis of DPN prevention and long-term management away from sole blood glucose control (Boulton

Table 3
The comparison of prevalence rates stratified by risk groups in FSCHE program.

Risk Group	Attendance Rate [b]	Primary and Secondary Outcomes	
		FSCHE Program Pooled (all investigated years)	
		DPN case/Whole population (%)	Length of hospital stay
All population	81.35 % (average)	728/2202 (33.1)	8.91 ± 0.073
High risk [a]		455/1257 (36.2)	9.05 ± 0.098
Low risk		273/945 (28.9)	8.74 ± 0.109
Year 2019			
		DPN case/Whole population	Length of hospital stay
All population	70.29 %	34/61 (55.7)	11.20 ± 0.433
High risk [a]		19/33 (57.6)	11.64 ± 0.648
Low risk		15/28 (53.6)	10.68 ± 0.549
Year 2020			
		DPN case/Whole population	Length of hospital stay
All population	78.59 %	63/133 (47.4)	11.10 ± 0.400
High risk [a]		40/76 (52.6)	11.59 ± 0.533
Low risk		23/57 (40.4)	10.44 ± 0.601
Year 2021			
		DPN case/Whole population	Length of hospital stay
All population	91.10 %	408/960 (42.5)	9.60 ± 0.117
High risk [a]		231/412 (56.1)	10.17 ± 0.185
Low risk		177/548 (32.3)	9.17 ± 0.148
Year 2022			
		DPN case/Whole population	Length of hospital stay
All population	80.89 %	74/301 (24.6)	8.58 ± 0.185
High risk [a]		51/191 (26.7)	8.65 ± 0.242
Low risk		23/110 (20.9)	8.45 ± 0.283
Year 2023			
		DPN case/Whole population	Length of hospital stay
All population	76.86 %	149/747 (19.9)	7.59 ± 0.086
High risk [a]		114/545 (20.9)	7.83 ± 0.104
Low risk		35/202 (17.3)	6.97 ± 0.139

Note:.

[a] Diabetes patients who tested positive for one or more indicators (such as Ankle-Brachial Index (ABI) $\langle$ 0.9 or ABI $\rangle$ 1.3, Vibration Perception Threshold (VPT) $\geq$ 15 Volts, or Electronic Skin Conductivity (ESC) $<$ 60 μSiemens) are classified as being at a high risk for DPN.

[b] The attendance rate is calculated by dividing the number of participants in the FSCHE program by the total number of inpatients in the Division of Endocrine and Metabolic Diseases at the Third Affiliated Hospital of Sun Yat-sen University. The data is sourced from the records maintained during the implementation process by nurses.

et al., 2005; Callaghan et al., 2012). Among them, diabetes health education plays an important role as a nurse-led intervention (ElSayed et al., 2023). In this study, the nurse team implemented diabetes health education as part of the FSCHE program, incorporating exercise and lifestyle education (Selvarajah et al., 2019). Personalized guidance plans were created by diabetes specialty nurses based on screening outcomes. These plans aimed to help patients adopt healthy diets, utilize health education tools, and implement structured exercise (Ahluwalia et al., 2013; Defeudis et al., 2018). The health education module additionally emphasizes maintaining ideal body weight, quitting smoking, limiting alcohol consumption, and managing emotions. The results of this study showed that diabetic patients who participated in the FSCHE program had significantly lower levels of metabolic indicators, such as triglycerides and total cholesterol, than patients in the routine nursing group. This may be attributed to the capacity of exercise to reduce blood glucose levels, improve indicators of lipid metabolism, enhance insulin sensitivity, and boost cardiopulmonary function (Allen et al., 2016). Additionally, adopting a healthy dietary pattern can mitigate inflammatory responses, while implementing calorie control in one's diet can alleviate weight issues and ameliorate metabolic disorders (Antoniazi et al., 2022; Nettleton et al., 2006). A reduction in triglyceride levels leads to an increase in the density of myelinated fibers in the sural nerve, which is regarded as a protective indicator for early-stage DPN (Van Acker et al., 2009; Wiggin et al., 2009). Also, interventions led by nurses have been found to have positive effects on BMI and the prevention and treatment of arterial plaques in participants with high-risk foot screening results.

Furthermore, diabetic patients in the FSCHE program demonstrated improved preservation of the glomerular filtration rate despite a lower initial rate. This discovery can be attributed to the ability of the FSCHE program to regulate blood glucose levels and lipid profiles, indirectly mitigating the formation of advanced glycation end products caused by hyperglycemia (Duffy et al., 2006; Saito et al., 2013). As a result, peripheral nerve oxidative and inflammatory stress is alleviated (Selvarajah et al., 2019). Additionally, the

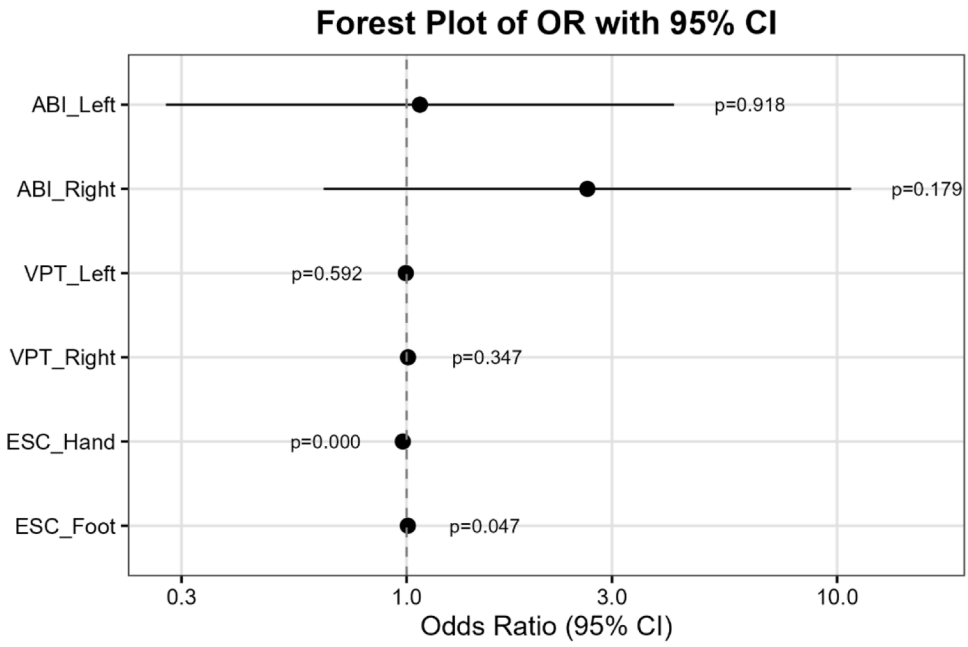

Fig. 2. Logistic regression results of foot screening indicators and DPN.
This forest plot illustrates the odds ratios (OR) with 95 % confidence intervals (CI) of foot screening indicators for the binary variable of DPN occurrence. ABI stands for Ankle-Brachial Index, VPT refers to Vibration Perception Threshold, and ESC denotes Electrochemical Skin Conductance. "Left" and "Right" indicate the left and right sides, respectively, while "Hand" represents the hand, and "Foot" refers to the foot. The model used is a logistic regression model.

combination of reduced inflammation and oxidative stress and improved control of blood glucose and lipid metabolism contributes to the enhancement of microvascular hemodynamics and an increase in glomerular filtration rate (Azab et al., 2012; Zitouni et al., 2020).

The International Working Group on the Diabetic Foot 2023 recommends integrating structured education with foot screening (Bus et al., 2024). Screening is performed to identify high-risk DPN patients at an early stage and offer preventive care that can effectively mitigate the risk of severe complications and shorten hospitalization durations. The promising results of our study highlight the effectiveness of the health education component of the FSCHE program for the multifactorial management of DPN.

4.1. Limitation

The 4721 patient samples included in this study were all obtained from real-world laboratory records, and because of the retrospective nature of the study, numerous confounding factors may have introduced certain biases. And there are limitations in drawing causal inferences regarding the effectiveness of the FSCHE program, a module clinic-based education program, as a tool for long-term behavior change in lifestyle modifications. Additionally, the patients included in this study were exclusively from the Third Affiliated Hospital of Sun Yat-sen University, and the FSCHE project was interrupted for a period in 2020 due to the impact of the pandemic COVID-19, which itself may have influenced the observations in this study. As a result, the prevalence of DPN and accuracy of screening are likely to be underestimated. In the future, we will conduct a randomized controlled trial to further observe the effectiveness of the FSCHE program in DPN, diabetic foot, and proliferative diabetic retinopathy.

5. Conclusion

In conclusion, the FSCHE program in our study integrated both nurse-led early foot screening and timely targeted health education in the management of diabetes and showed significant effects in reducing the prevalence of DPN and shortening hospitalization duration in patients with diabetes. Employing objective screening tools to detect DPN at an early stage, as well as the nurse-led interventions may prevent the progression of DPN.

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CRediT authorship contribution statement

Shuhong Liu: Writing – review & editing, Writing – original draft, Project administration, Investigation, Data curation, Conceptualization. **Hexiao Ding:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Dandan Li:** Writing – original draft, Project administration, Investigation, Data curation, Conceptualization. **Fen Lu:** Investigation, Data curation. **Gumei Luo:** Investigation, Data curation. **Yujin He:** Investigation, Data curation. **Hui Li:** Investigation, Data curation. **Xiuhong Zeng:** Investigation, Data curation. **Kaixin Li:** Investigation, Data curation. **Dong-E Gong:** Investigation, Data curation. **Xiling Hu:** Validation, Resources, Project administration, Conceptualization. **Yanming Chen:** Validation, Supervision, Resources, Project administration, Funding acquisition, Conceptualization. **Xubin Yang:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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