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Walking Strategy Abnormalities in Elderly with Diabetic Neuropathy: A Biomechanical Investigation through three Curves Analysis

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Abstract

Objective: The aim of the present study was to explore the walking strategy by monitoring the characteristics of plantar pressure in elderly patients with diabetic peripheral neuropathy.

Methods: This descriptive study was conducted at the endocrine ward at Huadong Hospital, Fudan University, shanghai, China, from April 2016 to December 2016. Elderly patients with diabetic peripheral neuropathy were enrolled from Huadong Hospital, Fudan University. Non-diabetes elderly were enrolled from Changning District Xianxia Street Community Service Center, Shanghai, China. A total of 229 participants were recruited. Non-diabetic elderly were grouped for DC, and elderly with type 2 diabetes, according to the Toronto clinical neuropathy score (TCSS) into no significant peripheral neuropathy group (DM group), mild peripheral neuropathy group (DN_1 group), moderate peripheral nerve lesion group (DN_2 group) and severe peripheral neuropathy group (DN_3 group), a total of five groups. Outcome measures included the center of pressure (COP), the plantar force time curve, the Foot balance curve and loading time.

Results:

COP trajectories: The COP trajectories in elderly with DPN were abnormal significantly with abnormal foldback, beginning point shifted forward and terminal point lateral shifted; The COP excursions along the medio-lateral axes reduced in elderly with DPN and increased in elderly without PN; The COP excursions and maximum excursions along the longitudinal reduced in elderly with DPN; The COP minimum excursions along the longitudinal axis increased in elderly with DPN, with the most severe PN significantly ($p<0.05$).

The plantar force time curve: The plantar force time curve were abnormal significantly in mild and severe PN with single more force peak; Among the morphologically normal curves, the first and second peak force reduced in elderly DM with PN and without PN. The time to peak and valley in elderly DM with PN and without PN delayed ($p<0.05$).

Foot balance: The Foot balance curve were abnormal significantly, with no positive wave or negative wave, with the most severe PN significantly. Among the morphologically normal curves, the positive and negative peak values reduced in elderly with DPN ($p<0.05$).

Loading time: Loading time was significantly longer in the severe PN; In the stance phase of gait cycle, the time of midstance phase were longer, and the time of heel contact phase and propulsion phase were shorter in elderly with DPN and without DPN, with moderate and severe PN more significant ($p<0.05$); The loading time of the whole foot were prolonged and advanced, The loading time of midfoot and heel were shorten ($p<0.05$).

Conclusions: The gait strategies in elderly with DPN were abnormal including shifted forward of the first loading site, lateral shifted of the final site, poor lateral stability and abnormal reentry, shortage driving force, plantar pressure loading offset, the prolonged loading time, prolonged stance phases and the forefoot ground ahead.

Keywords: Elderly; Diabetic peripheral neuropathy; Walking strategy

Introduction

In elderly diabetic patients, changes in gait features were related to characteristics such as aging and diabetes itself. For example, atrophied leg muscles and plantar fat pad, developped claw toes and hammer toes, Limited joint mobility [1], loss of plantar sensory, and reduced ability to readjust the way [2]. These structural and functional abnormalities of the foot were associated with changed walk strategy and abnormal gait [3].

The purpose of this study was to monitor the characteristics of COP and explored the walking strategy by measuring dynamic barefoot plantar pressure in elderly patients with type 2 diabetes. This would assist in providing the basis for the establishment of abnormal plantar pressure correction system, stability of their gait and reducing occurrence of falls.

Subjects and Methods

Subjects

This study was conducted at the endocrine ward at Huadong Hospital, Fudan University, shanghai, China, from April 2016 to October 2016. Two trained diabetes specialist nurses were responsible for the enrollment of the elderly patients with type 2 in Huadong Hospital, Fudan University. Another two trained diabetes specialist nurses were responsible for the enrollment of the non-diabetes elderly in District Xianxia Street Community Service Center, Shanghai, China. A total of 229 participants were recruited. Non-diabetic elderly were grouped for DC, and elderly with type 2 diabetes, according to the Toronto clinical neuropathy score (TCSS) into no significant peripheral neuropathy group (DM group), mild peripheral neuropathy group (DN_1 group), moderate peripheral nerve lesion group (DN_2 group) and severe peripheral neuropathy group (DN_3 group), a total of five groups. For the selection of the sample, the following factors were considered as inclusion criteria: the diagnosis of type 2 diabetes under stable metabolic control; age older than 60; capability to remain in an orthostatic position without assistance or the use of auxiliary devices; Individuals with current foot ulcer, bilateral foot amputations, wheelchair-bound or unable to walk, too sick to participate, or psychiatric illness that prevented informed consent were excluded. All subjects provided informed consent prior to participating in the study. The study protocol was approved by the Ethical Committee of Huadong Hospital, Fudan University.

Procedure

When the patients condition was stable, they would be required to fill in a general information form and undergo plantar pressure platform test. All these were done under the guidance of 6 trained diabetes specialist nurses in the department. The nurses who participated in the study are nurse-in-charge and above, and they have been working in the hospital for more than five years.

Instruments

General information form: Demographic characteristics regarding personal details such as gender, age, height and weight, without occupation, religious beliefs were record.

Plantar pressure platform: The platform was made of a matrix of resistive sensors spaced 40 cm x 100 cm with a sensor resolution of 4 sensors/cm^2 sampling at 300 Hz. The parameters were calibrated before measuring. The platform was inserted at a level in the middle of a wooden walkway that was long enough to guarantee that the acquisition was made "at regimen". The patient was trained to walk barefoot on the walkway at his or her preferred speed in a natural way and to center the active surface with one foot only without looking down at the platform. For each foot of each patient, ten specific subareas were accurately selected: The first toe (T1),The second to fifth toes (T2-5), The first metatarsal head (MH1), The second metatarsal head (MH2), The third metatarsal head (MH3), The fourth metatarsal head (MH4), The fifth metatarsal head (MH5), The midfoot (MF), The heel medial (HM), The heel lateral (HL). Outcome measures included: (1) COP trajectory (2) The plantar force time curve (3) Foot balance (4) Loading time.

Statistical methods

Sample size estimations: The sample size calculation was based on the curve peak and valley value of total foot pressure changes in DPN patients with different neuropathy degree measured by the plantar pressure test system which was done by Kun Wang [4]. We assumed that the significance level (α) is 0.05 and the permissible error (δ) is 0.1. With an expected dropout of 10% we chose randomly 245 patients in the trial. According to the proportional distribution formula of the sample size of each layer, we obtained that the numbers of the five groups were 73,29,63,48 and 32 respectively.

Statistical analyses: Data were analyzed using the SPSS statistical package (version 22.0). Data were reported as mean and SD or absolute and relative frequencies. The paired t-test was used for the comparison of the X, Y-axis displacement of the left and right foot. The normal distribution was confirmed for all data by an Anderson–Darling Normality test. A significance level of 5% was adopted.

Results

Demographic data

There were no significant differences in age, body mass index (BMI), waist-to-hip ratio (WHR), feet length, foot width and diabetes course, gender, educational level, smoking history, drinking history and foot deformity ratio (p>0.05) (Table 1).

Group	DC group (n=65)	DM group (n=27)	DN_1 group (n=60)	DN_2 group (n=48)	DN_3 group (n=29)	F (or x^2)	P
Age(year)	69.9 ± 5.8	69.7 ± 7.2	72.2 ± 7.4	73.4 ± 8.8	73.4 ± 8.9	2.386	0.052
Gender(male/female)	29/36	13/14	22/38	23/25	Oct-19	5.587	0.232
Education	7/39/19	2/17/8	9/32/18	7/34/17	7/16/6	8.546	0.382
Smoking history(yes/no)	5/60	4/23	6/54	10/38	2/24	5.204	0.267
Drinking history(yes/no)	7/58	1/26	7/53	4/44	3/26	1.586	0.811

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BMI(kg/m^2)	23.5 ± 2.4	20.3 ± 9.0	23.6 ± 5.3	22.0 ± 9.2	22.9 ± 5.1	1.643	1.164
WHR	0.8 ± 0.1	0.7 ± 0.3	0.8 ± 0.2	0.8 ± 0.2	0.8 ± 0.3	1.237	0.296
Foot length(cm)	21.7 ± 1.9	22.8 ± 1.2	21.9 ± 1.4	22.5 ± 1.9	21.9 ± 2.0	1.897	1.113
Foot width(cm)	4.8 ± 1.8	6.4 ± 1.6	5.3 ± 2.0	4.7 ± 2.7	5.0 ± 2.1	2.173	0.073
Foot deformity	20/45	7/18	16/44	20/28	9/20	3.093	0.542
Diabetes duration(year)	—	15.0 ± 9.0	15.6 ± 10.6	17.3 ± 10.6	17.1 ± 8.5	0.447	0.72

Table 1: The comparison of basic information between the five groups (n=229).

The center of pressure

The COP trajectories in elderly with DPN were abnormal significantly with abnormal foldback, beginning point shifted forward and terminal point lateral shifted. The COP excursions along the medio-lateral axes reduced in elderly with DPN and increased in elderly without PN; The COP excursions and maximum excursions along the longitudinal reduced in elderly with DPN; The COP minimum excursions along the longitudinal axis increased in elderly with DPN, with the most severe PN significantly (p<0.05) (Table 2 and 3).

Group	Cases (n)	Starting point	Lift off point	Fold back
DC	65	5(7.7)	21(32.3)	7(10.8)
DM	27	3(11.1)	11(40.7)	6(22.2)
DN1	60	7(11.7)	29(48.3)	16(26.7)[a]
DN2	48	12(25.0)[a]	24(50.0)[a]	15(31.3)[a]
DN3	29	8(27.59)[a]	19(65.52)[a]	10(34.48)[a]
X^2	-	10.752	10.083	9.745
P	-	0.029*	0.039*	0.045*
Note: *p<0.05: Compared with DC group;[a]p<0.05: Compared with DM group; [b]p<0.05:Compared with DN1 group; [c]p<0.05				

Table 2: The proportion of the abnormal COP trajectory between the five groups (n (%)).

Group	Cases (n)	The X axis displacement	The maximum value of Y axis	The minimum value of Y axis	The Y axis length
DC	65	32.1 ± 8.7	203.3 ± 26.6	29.2 ± 11.2	174.1 ± 28.8
DM	27	39.0 ± 8.1[a]	197.4 ± 20.5	30.8 ± 12.1	166.6 ± 30.1
DN_1	60	27.6 ± 10.6[ab]	190.5 ± 28.1[a]	35.7 ± 16.2[a]	154.7 ± 41.4[a]
DN_2	48	27.4 ± 12.4[ab]	187.2 ± 26.1[a]	35.8 ± 15.2[a]	151.4 ± 35.1[a]
DN_3	29	24.4 ± 11.2[ab]	183.5 ± 38.2[a]	44.7 ± 31.8[abcd]	138.8 ± 64.9[ab]
F	-	7.169	3.831	4.52	5.065
P	-	0.000*	0.005*	0.002*	0.001*
Note: *p<0.05: Compared with DC group; [a]p<0.05: Compared with DM group; [b]p<0.05: Compared with DN1 group; [c]p<0.05: Compared with DN2 group; [d]p<0.05					

Table 3: The displacement on the X axis and Y axis of the COP trajectory between the five group (mm).

The plantar force time curve

The plantar force time curve were abnormal significantly in mild and severe PN with single more force peak; Among the morphologically normal curves, the first and second peak force reduced in elderly DM with PN and without PN. The time to peak and valley in elderly DM with PN and without PN delayed (p<0.05) (Table 4).

Group	Cases (n)	A single peak	More than one peak
DC	65	6(9.2)	7(10.8)
DM	27	1(3.7)	5(18.5)
DN_1	60	13(21.6)^{ab}	7(11.7)
DN_2	48	12(25.0)^{ab}	9(18.8)
DN_3	29	8(27.6)^{abc}	12(41.4)a
X^2		928	909.7
P		0.000*	0.000*
Note*p<0.05: Compared with DC group; ^{a}p<0.05: Compared with DM group; ^{b}p<0.05: Compared with DN1 group; ^{c}p<0.05: Compared with DN2 group; ^{d}p<0.05			

Table 4: The proportion of the abnormal all foot pressure curve between the five groups ((n) (%)).

Foot balance

The foot balance curves were abnormal significantly, with no positive wave or negative wave, with the most severe PN significantly. Among the morphologically normal curves, the positive and negative peak values reduced in elderly with DPN ($p<0.05$) (Table 5 and 6).

Group	Cases (n)	Not negative wave	Not positive wave
DC	65	9(13.8)	7(10.8)
DM	27	4(14.8)	3(11.1)
DN_1	60	13(21.7)	18(66.7)^{ab}
DN_2	48	13(27.1)	15(31.3)^{ab}
DN_3	29	11(37.9)^{ab}	11(37.9)^{ab}
X^2	-	9.541	15.09
P	-	0.049*	0.005*
Note*p<0.05: Compared with DC group; ^{a}p<0.05: Compared with DM group; ^{b}p<0.05: Compared with DN1 group; ^{c}p<0.05			

Table 5: The proportion of the abnormal foot balance curve between the five groups (n(%)).

Group	Cases (n)	Negative peak	Positive peak
DC	49	0.73 ± 0.27	1.36 ± 0.58
DM	20	0.49 ± 0.27	0.94 ± 0.58
DN_1	29	0.40 ± 0.05	0.85 ± 0.26a
DN_2	20	0.53 ± 0.28	0.86 ± 0.59a
DN_3	7	0.57 ± 0.49	0.57 ± 0.34a
F		2.403	2.877
P		0.055	0.027*
Note: *p<0.05: Compared with DC group; ^{a}p<0.05			

Table 6: The negative peak and positive peak in normal foot balance curve between the five groups (%).

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Loading time

Loading time was significantly longer in the severe pain. In the stance phase of gait cycle, the time of midstance phase were longer, and the time of heel contact phase and propulsion phase were shorter in elderly with DPN and without DPN, with moderate and severe PN more significant (p<0.05); The loading time of the whole foot were prolonged and advanced, the loading time of midfoot and heel were shorten (p<0.05) (Table 7).

Group	T1	T2-5	M1	M2	M3	M 4	M5	MF	HM	HL
DC	43.9 ±2 8.9	34.8 ± 25.9	19.1 ± 15.4	45.3 ± 27.5	51.6 ± 20.7	50.8 ± 24.8	30.7 ± 26.7	8.5 ± 1.4	3.4 ± 1.9	4.3 ± 1.5
DM	46.9 ± 24.1	22.4 ± 18.2	39.8 ± 24.4a	39.6 ± 19.3	34.8 ± 16.8a	42.2 ± 17.2	44.4 ± 26.1	15.1 ± 12.0	0.8 ± 0.5	1.1 ± 0.7
DN_1	45.1 ± 28.9	38.6 ± 28.6	35.2 ± 28.4[a]	36.2 ± 21.9[ab]	31.5 ± 21.6[a]	31.8 ± 23.8[a]	27.3 ± 18.4[b]	14.9 ± 8.7	4.3 ± 2.7	3.9 ± 1.2
DN_2	34.6 ± 26.4[abc]	22.4 ± 10.5	28.8 ± 24.6[ab]	28.4 ± 20.8[a]	26.9 ± 17.8[a]	34.9 ± 23.0[a]	20.9 ± 10.3[b]	15.1 ± 8.7	2.7 ± 1.4	1.7 ± 0.3
DN_3	30.6 ± 26.1[abc]	32.9 ± 20.2	23.8 ± 15.2[bc]	35.3 ± 23.1	31.8 ± 21.4[a]	37.6 ± 22.0[a]	27.8 ± 24.3[b]	15.9 ± 9.8	1.9 ± 0.9	2.0 ± 0.5
F	2.49	2.138	4.645	3.816	13.26	6.18	3.771	1.956	0.937	1.76
P	0.044*	0.077	0.001*	0.005*	0.000*	0.000*	0.005*	0.102	0.443	0.138
Note*p<0.05: Compared with DC group; [a]p<0.05: Compared with DM group; [b]p<0.05: Compared with DN1 group; [c]p<0.05										

Table 7: The initial landing time in each region of foot between the five groups (%).

Discussion

Shortage driving force in elderly with DPN

This study showed that the COP trajectories in elderly with DPN were abnormal significantly with abnormal foldback, and the plantar force time curve were abnormal significantly in severe PN with more force peak. These findings are in line with Qicheng Qing et al, [5]. The foot-ground reaction force is used to produce the body center of gravity of displacement and acceleration on foot to move forward [6]. The abnormal foldback might be associated to delayed activation of ankle plantar flexions and weakened Lower extremity muscle strength, which were not enough to provide continuous propulsion and energy to insure weight forward, particularly from the talus to the metatarsal, eventually leading the body to moving a certain distance backward and then forward to get enough forward momentum in compensation [7]. This may be the compensatory gait in order to make the body center of gravity forward in old patients with DPN. This adaptive change of compensatory gait to the patients with diabetes can make patients get more stable gait, prevent fall, etc.

Poor lateral stability in elderly with DPN

This study showed that the COP excursions along the medio-lateral axes reduced in elderly with DPN and increased in elderly without PN.COP trajectory in the displacement on the X axisis the foot slope movement in the state of supporting on one foot [8]. In normal gait cycle, COP is the real-time dynamic adjustment and compensation of neuromuscular control system to the body center of mass, remaining at certain dynamic stability region, too big or too small will be out of balance [9]. In the aspect of the center of gravity instability, the elderly DM patients can compensate for the balance of the ankle movement by compensating the gait of the ankle joint by maintaining the sensation of the foot feeling, and maintaining the relative position of the COP change [10]. Elderly patients with DPN cannot accurately perceive changes in the body center of gravity and timely realization of the adjustment and compensation of the center of gravity because of diminished or missing plantar sensation and limited ankle range, resulting in poor lateral balance control. Studies had shown that the inter-external body instability more likely to lead to fall than the anteroposterior side of the body instability, which led to the lateral fall is the main cause of hip fracture in the elderly.

Lift off outwards in elderly with DPN

The Foot balance curve were abnormal in the most severe PN significantly without positive wave, and of the normal curve pressure load move outside in the stride phase, meanwhile, the COP showed that the percentage of abnormal liftoff point was higher in elderly with DPN [11]. These indicated that forefoot moved outside in the stride phase in elderly with DPN, including displacement and pressure load outside. As Ding et al. found the COP trajectory ended on the non-hallux deviating from T1 to T2-5 in the peripheral neuropathy. Because of limited first toe joint mobility in elderly patients with diabetes, Plantar load can't be transferred from the outside to the inside, leading to increased reliance on outside [12]. Abnormal terminal point can increase energy consumption, hinder the weight forward during toe-off phase and cause the elderly with DPN fall further.

Flat-footed contact in elderly with DPN

This study showed that the length of the COP excursions on the on the Y axis Significantly reduced and the minimum value increased significantly. The time of much of the front feet on the ground were ahead of time. The proportion of the plantar pressure curve that had a single peak was higher. The landing time of the foot of each area was longer. All of these suggested that initial landing site moved forward, and tend to all foot touch down. As Ding et al. observe the curves of the pressure center of gravity changes over time and the landing time of foot of each area in 136 cases of elderly patients with diabetes, and found People with diabetes tended to all foot touchdown [12]. PN cause ankle range reduced and lower limb muscle activation delayed, Foot followed to the extent of the ankle dorsiflexion and knee-sprung degree is reduced, makes the individual heel "stamp" and the forefoot faster earlier on [13]. This could make a foot to stress buffer effect poor and the stability of the ground reduced. At the same time, leading to the body center of gravity forward, supporting period stability decreased and risk of falls increased.

Conclusion

The walking strategy in elderly with DPN were abnormal including shortage driving force, poor lateral stability, liftoff outwards and flat-footed contact. Proprioception training, personalized ankle brace, plantar orthopedic insoles and Lower limb muscle strength training that can strengthen input and feedback of the plantar tactile sensor and the lower limb muscle strength may be able to improve the gait control strategy and reduce falls and promote disease rehabilitation.

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