糖尿病足

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2型糖尿病周围神经病变和步态、平衡能力的关系研究

邓 芳[1],邓武权[2],何 敏[1],吴绮楠[1],陈 兵[1]

(1. 第三军医大学西南医院内分泌科,重庆 400038;
2. 重庆市急救医疗中心/重庆市第四人民医院内分泌肾内科,重庆 400041)

【摘 要】**目的**:探讨2型糖尿病周围神经病变(diabetic peripheral neuropathy,DPN)与步态、平衡能力的关系。**方法**:收集年龄匹配住院2型糖尿病患者108例,根据DPN症状、体征和神经传导速度(nerve conduct velocity,NCV)分为3组。A组:无DPN症状体征和NCV异常,共35例;B组:无DPN症状体征但有NCV异常,共34例;C组:有症状体征和NCV异常,共39例。分析比较组间步态和平衡能力参数以及与NCV的关系。**结果**:(1)3组糖化血红蛋白水平依次增高[(8.01±2.13) vs. (9.10±1.83) vs. (9.25±2.19)]($P<0.05$),C组糖尿病视网膜病变明显高于其余2组(20.0% vs. 14.7% vs. 41.0%)($P<0.05$)。(2)C组步速身高比明显低于其余2组[(0.49±0.14) vs. (0.52±0.10) vs. (0.44±0.11)]($P<0.05$),其他步态参数均无统计学差异。(3)无论睁眼还是闭眼,C组身体前后摇摆幅度均明显高于A组。在睁眼时,C组踝关节前后摇摆幅度明显高于A组[(1.10±0.41) vs. (1.26±0.52) vs. (1.46±0.62)]($P<0.05$),C组踝关节摇摆指数明显高于其余2组[(0.15±0.06)vs. (0.16±0.07) vs. (0.19±0.09)]($P<0.05$)。在闭眼时,C组髋关节摇摆区域明显高于其余2组[(1.21±0.74) vs. (1.31±0.81) vs. (2.36±0.78)]($P<0.05$);C组髋关节摇摆指数明显高于A组[(0.22±0.08) vs. (0.22±0.06) vs. (0.29±0.15)]($P<0.05$)。(4)3组患者闭眼身体摇摆率均明显高于睁眼,软地身体摇摆率明显高于硬地。改良感觉整合平衡测试提示,软地时无论睁眼还是闭眼,C组身体摇摆率明显高于A组。**结论**:中老年2型糖尿病合

作者介绍:邓 芳,Email:cqdf2016@126.com,
研究方向:内分泌与代谢病。

通信作者:陈 兵,Email:chenbing3@medmail.com.cn。

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并临床显性周围神经病变可降身体平衡稳定性，踝关节和髋关节代偿策略可改善这种减弱以保持稳定。因此，采用新型监测技术为进一步干预防治提供依据，可能是早期预防跌倒的关键。

【关键词】2 型糖尿病；周围神经病变；步态特征；平衡能力；神经传导速度
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Association between diabetic peripheral neuropathy and gait as well as balance performance in patients with type 2 diabetes mellitus

Deng Fang[1], *Deng Wuquan*[2], *He Min*[1], *Wu Qinan*[1], *Chen Bing*[1]

(*1. Department of Endocrinology, Southwest Hospital, The Third Military Medical University, Chongqing;*
2. Department of Endocrinology and Nephrology, Chongqing Emergency Medical Center/
The Fourth People's Hospital of Chongqing)

【Abstract】***Objectives***: To investigate the association of diabetic peripheral neuropathy (DPN) and biomechanics parameters such as gait and balance performance in patients with type 2 diabetes mellitus (T2DM). ***Methods***: A cohort of 108 hospitalized T2DM patients with age-matched were admitted at southwest hospital. The subjects were divided into 3 groups based on nerve conduct velocity (NCV) and clinical symptoms or sign of DPN. The differences of biomechanics parameters were analyzed between groups, as well as the relationship with NCV. ***Results***: (1)The hemoglobin A1c was gradually increased[(8.01 ± 2.13) vs. (9.10 ± 1.83) vs. (9.25 ± 2.19)] ($P < 0.05$) from group A to group C. The prevalence of diabetic retinopathy was significant higher in group C than in other two groups (20.0% vs. 14.7% vs. 41.0%) ($P < 0.05$). (2)In terms of gait parameters, the stride length/height was significant higher in group C than in other two groups[(0.49 ± 0.14) vs. (0.52 ± 0.10) vs. (0.44 ± 0.11)] ($P < 0.05$). However, no significant difference was observed in other gait parameters. (3)In terms of static stand balance parameters, no matter eyes open or closed, the posteroanterior sway range of center of mass (CoM) in group C was significant higher than that of group A. The posteroanterior sway range of ankle angle with eyes open in group C was significant higher than that of group A[(1.10 ± 0.41) vs. (1.26 ± 0.52) vs. (1.46 ± 0.62)] ($P < 0.05$); the sway index of ankle angle with eyes open in group C was significant higher than those of other two groups[(0.15 ± 0.06) vs. (0.16 ± 0.07) vs. (0.19 ± 0.09)] ($P < 0.05$). The sway area of hip angle with eyes closed in group C was significant higher than those of other two groups[(1.21 ± 0.74) vs. (1.31 ± 0.81) vs. (2.36 ± 0.78)] ($P < 0.05$). The sway index of hip angle with eyes closed in group C was significant higher than that of group A[(0.22 ± 0.08) vs. (0.22 ± 0.06) vs. (0.29 ± 0.15)] ($P < 0.05$). (4)The sway range of CoM in all three groups with eyes closed or standing at hard surface were significant higher than that with eyes open or standing at soft surface, respectively. In modified clinical test of sensory interaction and balance (CTSIB) test, both eyes open or closed, the sway index of CoM in group C was significant higher than that of group A when stood on soft surface. ***Conclusion***: DPN with overt clinical symptoms could decrease body balance stability under different circumstances in middle-aged and elder patients with T2DM. Ankle and hip joints compensatory strategies could improve the balance dysfunction in order to keep balance stability. Therefore, early detection with novel technology combined with preventive intervention may be a crucial measure for fall prevention.

【Key words】type 2 diabetes mellitus; peripheral neuropathy; gait characteristics; balance ability; nerve conduct velocity

2型糖尿病患者步态特征和平衡能力改变，可引起活动能力和平衡稳定性下降，导致跌倒、外伤甚至骨折[1-3]。糖尿病引起伤害性跌倒风险明显增加，可达每年 1.25 次/人[2]，老年患者跌倒风险更是剧增[4]。周围神经病变可加重糖尿病步态和平衡稳定性损害，诱发足溃疡和跌倒发生[5-6]。然而，既往研究提示，步态和身体稳定性改变可出现在糖尿病周围神经病变（diabetic peripheral neuropathy，DPN）前期[7-9]。步态改变增加跌倒风险引起医疗费用支出也显著增加[10]，因此早期识别糖尿病足生物力学异常至关重要。

近些年来，随着微型传感技术的发展，加速度传感器已广泛应用于人体运动学测试，可同时测量全身不同部位直线加速度和评估身体平衡控制能力[11]。与压力板测试对照研究提示，糖尿病患者的重心（center of mass，CoM）和足底压力中心（center of pressure，CoP）之间呈良好的线性相关，提示可用于人体平衡性和体位控制代偿策略监测[12]。DPN 通常需要根据患者临床症状、体征、振动感觉阈值（vibrating perception threshold，VPT）和神经传导速度

(nerve conduct velocity,NCV)等诊断。糖尿病所致生物力学改变可发生在显性 DPN 临床症状前,早期监测和识别该类患者的步态和平衡异常可预防性干预减少溃疡、跌倒和外伤等并发症。迄今,国内尚未见使用穿戴式加速度传感器对 2 型糖尿病以及神经病变的生物力学监测研究。因此,本研究旨在利用穿戴式加速度传感器评估 2 型糖尿病患者的生物力学参数,分析不同临床表现和体征的 DPN、NCV 和步态、平衡能力等参数的关系。

1 对象与方法

1.1 对象和分组

来自我院内分泌科 2016 年 1 月至 12 月的住院 2 型糖尿病患者 108 例,符合 1999 年世界卫生组织(WHO)关于糖尿病的诊断标准,其中男性 56 例,女性 52 例;年龄 29~91 岁,平均(60.76 ± 10.68)岁;病程 0~25 年,平均(8.18 ± 5.93)年。纳入标准包括:2 型糖尿病、18~70 岁、体质指数(body mass index,BMI)18~35;排除标准包括:无法独立活动或者行走、任何部位的下肢截肢(趾)、明显足部畸形(如夏科氏关节病)、活动下肢溃疡、脑损伤史(外伤、炎症、结核、肿瘤、癫痫等)、视力低下(戴镜能矫正可纳入)、脊柱疾病(外伤、结核、肿瘤、椎间盘突出等)、酗酒症、肝肾功能不全、有毒物质接触者、脏器感染、妊娠、特殊类型糖尿病、糖尿病急性并发症、HIV 阳性者。DPN 的临床症状和体征包括:①温度觉异常;②尼龙丝检查,足部感觉减退或消失;③振动觉异常;④踝反射消失。其中,39 例伴有 2 种及其以上症状或体征,占 36.11%。NCV 检查有 2 项及其以上异常者提示 NCV 阳性。

根据患者 DPN 临床症状、体征和 NCV 情况分为 3 组,A 组:无 DPN 症状体征和 NCV 异常,共 35 例;B 组:无 DPN 症状体征但有 NCV 异常,共 34 例;C 组:有症状体征和 NCV异常,共 39 例。研究已通过西南医院伦理备案,并获得所有试验者的知情同意书。

1.2 数据收集和检测方法

1.2.1 病史资料 收集患者年龄、性别、病程、BMI、腰臀比、糖尿病视网膜病变、高血压病史、踝臂指数(ankle-brachial index,ABI);采用层析法测定糖化血红蛋白(glycosylated hemoglobin,HbA1c);多普勒超声血液流动探测器测定踝部收缩压与肱动脉收缩压,两者之比为该侧下肢 ABI。

1.2.2 NCV 测定 使用 Keypoint 全功能肌电图/诱发电位仪(Alpine BioMed ApS,Denmark)专人检测。患者仰卧于安静房间中,环境温度 22 ℃~25 ℃,分别测量正中神经、尺神经、胫神经、腓总神经及腓肠神经的传导功能。测量的电生理参数包括运动神经传导速度、运动远端潜伏期以及复合肌肉动作电位波幅(远、近端);感觉神经传导速度、感觉神经动作电位波幅;正中神经 F 波最短潜伏期及胫神经 H 反射潜伏期,共计 26 项,其中传导速度减慢、波幅下降或潜伏期延长视为 NCV 异常。正常范围参照我院肌电图室按不同年龄组分别建立的标准。

1.2.3 生物力学参数测定 使用 LEGSys(BioSensics LLC,USA)和 BalanSens(BioSensics LLC,USA)评估步态和平衡功能。步态主要参数包括步长、步高比、步时、步速、步速身高比、步频、步态周期的支撑相和摆动相等;平衡性主要参数包括重心位移、踝角度和髋角度(左右幅度、前后幅度、摇摆面积、摇摆指数、摇摆速度)等。步态评估方法采用习惯性地面正常速度行走,将 2 个传感器分别置于患者小腿前方固定,每次测定时间为 60 s[13]。平衡能力检测采用硬地站立睁闭测试和改良感觉整合平衡测试 (mCTSIB)测试[14]。硬地站立睁闭眼测试是指被检测者双手交叉置于胸前,平视前方保持站立状态下睁闭眼各 15 s,一个传感器固定置于患者小腿前方,另一个固定在患者脐平面前方。mCTSIB 测试是指被检测者连贯依次序站立于硬地、软垫上的睁、闭眼四种状态测试各 30 s,传感器与硬地站立睁闭眼测试相同。每个新测试前让患者练习测试过程 2 次。上述检测中所有数据均通过感应器探头发射至蓝牙实时将数据传送至电脑的配套分析软件。

1.3 统计学方法

使用 SPSS 20.0 软件录入数据和统计分析。非正态分布变量采取平方根、对数转换后再行统计学分析;计量资料以均数 ± 标准差($\bar{x} \pm s$)表示。组间比较采用单因素方差分析,两两比较用 SNR-q 检验;计数资料以百分率表示,组间比较用χ^2 检验。检验水准 α=0.05。

2 结 果

2.1 各组临床资料比较

3 组间的年龄、病程、性别、腰臀比、高血压病史和双侧 ABI 均无统计学差异;3 组 HbA1c(%)依次增高,BC 2 组较 A 组更高($P < 0.05$);C 组糖尿病视网膜病变明显高于 A 和 B 2组($P < 0.05$)。见表 1。

2.2 各组间步态参数比较

C 组患者的步速身高比明显低于 A 组患者($P < 0.05$)。

2.3 各组硬地站立测试参数比较

无论睁眼还是闭眼,C 组患者的身体前后摇摆幅度明显高于 A 组($P < 0.05$)。在睁眼时,C 组患者的踝关节前后摇摆幅度明显高于 A 组($P < 0.05$);同时 C 组患者踝关节摇摆指数明显高于其余 2 组($P < 0.05$)。在闭眼时,C 组患者的髋关节摇摆区域明显高于其余 2 组($P < 0.05$);同时 C 组患者的髋关节摇摆指数明显高于 A 组($P < 0.05$)。见表 2。

2.4 各组 mCTSIB 摇摆指数比较

3 组患者无论是硬地还是软地,闭眼时的摇摆率均高于睁眼,且软地的摇摆率明显高于硬地。在软地情况,无论睁眼还是闭眼,C 组患者的身体摇摆率明显高于 A 组($P < 0.05$)。见图 1。

表 1　3 组患者一般资料比较

Tab.1　Comparison on general data of three groups

一般资料	A组（n=35）	B组（n=34）	C组（n=39）	χ^2/F 值	P 值
年龄(岁)	55.34 ± 11.68	57.82 ± 8.62	59.48 ± 9.01	1.640	0.198
病程(年)	8.49 ± 6.27	7.89 ± 4.91	9.33 ± 6.22	2.410	0.095
人数(男/女)	35（19/16）	34（17/17）	39（20/19）		
性别(女)(%)	45.71	50.00	48.72	0.140	0.935
腰臀比	0.92 ± 0.08	0.92 ± 0.05	0.93 ± 0.05	0.310	0.731
DN(%)	20.0	14.7	41.0[ab]	3.810	0.035
HTN(%)	28.57	52.94	38.46	4.320	0.115
ABI 左	1.08 ± 0.06	1.08 ± 0.07	1.10 ± 0.11	0.880	0.417
ABI 右	1.09 ± 0.06	1.08 ± 0.08	1.36 ± 1.49	1.170	0.314
HbA1c(%)	8.01 ± 2.13	9.10 ± 1.83[a]	9.25 ± 2.19[a]	3.800	0.025

注：与 A 组比较，a：P<0.05；与 B 组比较，b：P<0.05

表 2　3 组硬地站立睁闭眼测试比较（$\bar{x} \pm s$）

Tab.1　Comparison on results of eyes open or closed tests（$\bar{x} \pm s$）

	项目	A组（n=35）	B组（n=34）	C组（n=39）	F 值	P 值
睁眼	前后摇摆（cm）	0.64 ± 0.21	0.74 ± 0.28	0.79 ± 0.28[a]	3.300	0.041
	踝前后摇摆（度）	1.10 ± 0.41	1.26 ± 0.52	1.46 ± 0.62[a]	4.550	0.013
	踝摇摆指数（度）	0.15 ± 0.06	0.16 ± 0.07	0.19 ± 0.09[ab]	3.900	0.023
闭眼	前后摇摆（cm）	0.71 ± 0.32	0.79 ± 0.30	0.91 ± 0.40[a]	3.130	0.048
	髋摇摆区域（cm^2）	1.21 ± 0.74	1.31 ± 0.81	2.36 ± 0.78[ab]	3.310	0.041
	髋摇摆指数（度）	0.22 ± 0.08	0.22 ± 0.06	0.29 ± 0.15[b]	4.890	0.009

注：与 A 组比较，a：P<0.05；与 B 组比较，b：P<0.05

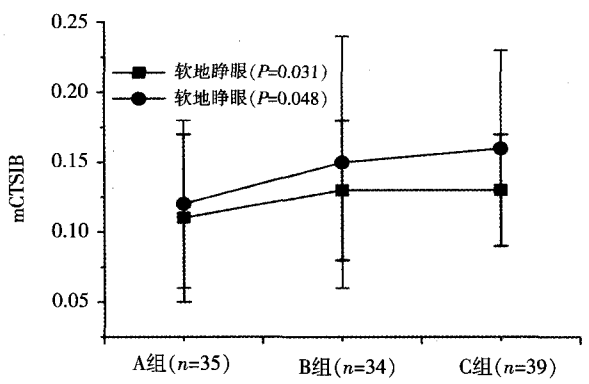


图 1　3 组 mCTSIB 摇摆指数比较

Fig.1　Comparison on mCTSIB test results of three groups

3　讨　论

WHO和糖尿病防治指南均推荐，糖尿病患者应进行规律日常活动，建议运动频率为每周 6 d 每次 30 min，但目前对运动前的运动能力和安全性评估却关注极少。步态改变所致跌倒引起外伤、骨折、心脑血管的医疗费用支出明显增加[15]。本研究中糖尿病视网膜病变在伴有临床症状的 DPN 患者中发病最高，二者均受糖尿病微血管病变影响，且既往研究提示视网膜病变引起的视力下降可影响和限制患者的活动能力，且使患者更为担心跌倒[16]。既往研究也提示通过本研究发现，伴有临床症状和神经传导异常的 2 型糖尿病周围神经损害患者，无论步态特征还是平衡能力均较非临床表现的 DPN 患者下降，尤其是平稳能力下降更为显著。与 Allet[1]、Katoulis[5]和 Lim[17]等报道相似。本研究是首次利用穿戴式加速度传感器（惯性测量单元）对中国糖尿病人群的步态和平衡能力进行检测，与既往其他研究结果相似。这也是首次对不同临床表现和体征的 2 型 DPN，在伴或不伴 NCV 异常时通过穿戴式加速度传感器检测生物力学的研究。本研究使用的穿戴式加速度传感器是 2010 年 Najafi 等[18]首先用于糖尿病患者的生物力学测定。该检测设备和足底压力板对照研究提示，无论糖尿病还是正常对照者的 CoM 和 CoP 间均呈良好的线性关系，提示可用于人体步态和平衡能力检测。该设备是由三轴陀螺仪和三轴加速度计组合而成。陀螺仪利用惯性原理测角

速度，加速度传感器利用力平衡原理测线性加速度。加速度计在较长时间中准确性高，而在较短时间内由于信号噪声存在而有误差。陀螺仪在较短时间内比较准确，而较长时间有漂移而存有误差。因此，加速度计和陀螺仪配合使用取长补短来确保测量准确可靠。该便携式设备的应用大大简便了既往繁琐的操作步骤，也大大减少了人为因素的影响。

在本研究中，糖尿病神经损害的步态特征仅有轻微的变化，其中仅有步速身高比出现差异性改变。在其他步态指标中，尽管未见显著性差异，有临床表现的神经损害人群的步长身高比、步时、步速和步频较其他对照人群更低，究其原因考虑与患者年龄轻，病程短有关。糖尿病步态异常与患者足部肌无力，神经病变严重程度有关。随着病程间延长，肌肉质量逐渐下降，可影响患者的运动能力，步态不稳甚至及跌倒[19]。糖尿病感觉运动神经病变患者有明显的步态改变，步速和步幅均降低[1,5]。因此有待随患者病程和年龄增加进一步观察步态变化。

研究提示，无论静态硬地直立还是硬、软地序贯变化，合并有症状和神经传导异常的糖尿病神经病变患者身体的摇摆幅度更大，摇摆率更强，平衡性稳定性更差。研究结果与 Strotmeyer[9]、Donoghue[16]、Yamamoto[20]、Herrera-Rangel[21]等研究报道一致，周围神经损害在糖尿病导致的不稳中具有极其关键的作用。目前尚无直接用于预测糖尿病患者跌倒的工具，研究提示身体平衡性降低和跌倒风险直接相关[22-23]。因此，身体平衡能力常用于预测患者跌倒的风险。老年糖尿病患者平衡功能减退更为明显，感觉神经缺失者跌倒风险高达 5 倍[4,24-25]。本研究同时发现，具有临床症状和体征以及神经传导异常的糖尿病周围神经损害患者在闭眼时，身体的摇摆性更高，稳定性更差，提示患者中枢性平衡控制能力下降。身体平衡控制通过高级中枢神经感觉反馈途径和外周局部位置相关性肌肉控制[26-27]。中枢控制机制则是依赖感觉反馈的长程躯体稳定调控[26,28]。感觉系统由视觉，前庭和体感组成，平衡的控制依赖上述各系统的共同作用，是平衡控制的关键。本研究中闭眼时视觉下降引起中枢神经感觉反馈途径减退，为了保持身体稳定性而通过增强外周代偿策略。睁眼时的外周代偿策略通过踝关节补偿，而闭眼时则通过髋关节策略补偿。从睁眼到闭眼这一过程，随着身体不稳定加重，身体启动更为接近重心的大关节进行补偿进一步加强稳定性而避免跌倒。相反的是，若 DPN 患者外周控制策略障碍时，同样可以通过中枢控制机制进行弥补促进机体稳定[29-30]。

本研究结果提示，中老年糖尿病周围神经损害患者主要表现为平衡稳定性障碍。尽管神经损害患者步态能力改变不明显，考虑研究的局限性有关。第一，病例样本数偏少，有待进一步扩大；第二，患者年龄偏小，尚未出现糖尿病神经病变引起足部肌无力、肌萎缩导致步态改变；第三，本研究尚未进行神经病变严重程度的评估，如 VPT 检查。糖尿病患者跌倒与多因素有关，早期发现并根据个体情况制定对应防治策略是预防跌倒发生的关键。系统性防治项目，包括检视使用药物，平衡练习和意识训练均有助于减少跌倒[31]。随着技术发展，小型便携式的生物力学评估仪不断出现，通过早期评估并给予矫正可带来益处。Grewal 等[32]基于体感传感器监测，通过视觉反馈训练下肢关节，提示可改善 DPN 患者躯体稳定减少摔倒，可能机制包括改善了皮肤神经损害，足部压力重分布、肌肉长度和紧张度等[32-33]。目前国内关于糖尿病足部生物力学的研究数据有限，能否通过合适的干预措施减少不稳尚不得而知。因此，结合目前的研究结果，将进一步探寻适合 DPN 人群的训练方式和矫正手段，以改善中老年糖尿病患者的身体稳定性，预防跌倒等严重并发症。

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