

脑卒中的心血管康复现状与进展

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【摘要】 脑卒中是一种由多种血管性危险因素引起的临床综合征, 患者常因肢体活动障碍而需长时间卧床, 日常活动受限, 增加了其心血管病发生的风险。同时, 大部分脑卒中患者合并有心血管疾病, 多数表现为心功能不全或无症状心功能不全。因此, 脑卒中的心血管康复是康复治疗中不可忽视的重要部分, 对脑卒中患者进行包括静息心电图、心脏彩色多普勒超声检查、运动负荷心电图、心肺运动试验、定距离测定 (6 min 步行试验、10 m 步行试验) 等心功能评估, 按照安全有效的运动处方进行规范的心血管康复治疗, 有助于改善脑卒中患者的预后及预防其复发。

【关键词】 脑卒中; 心血管康复; 心肺运动试验; 运动负荷试验; 运动治疗

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【Abstract】 Stroke is a clinical syndrome caused by a variety of vascular risk factors. Patients with stroke have to rest in bed due to physical activity barriers, which limit their daily activity and increase the risk of cardiovascular diseases. Meantime, a majority of stroke patients are complicated with cardiovascular diseases, mainly manifested with cardiac insufficiency or asymptomatic cardiac insufficiency. Therefore, rehabilitation of cardiovascular diseases is an essential part of rehabilitation therapy for patients diagnosed with stroke. It is necessary to perform resting electrocardiogram, cardiac color doppler ultrasound, exercise load electrocardiogram, exercise cardiopulmonary test, fixed-distance walking test (6-minute or 10-meter walking test) and alternative cardiac function evaluation for stroke patients. Standard rehabilitation therapy of cardiovascular diseases should be delivered according to safe and effective prescription, which contributes to improving clinical prognosis and preventing stroke recurrence.

【Key words】 Stroke; Rehabilitation of cardiovascular disease; Cardiopulmonary exercise testing; Exercise tolerance test; Exercise therapy

脑卒中是一种由多种血管性危险因素引起的临床综合征, 患者普遍存在冠状动脉粥样硬化性心脏病 (冠心病)、高血压病、糖尿病、脂肪代

谢紊乱以及心功能不全等心血管和代谢性疾病, 控制这些危险因素在脑卒中的康复治疗中具有极其重要的意义^[1]。

一、脑卒中与心血管和代谢性疾病

1. 脑卒中与心脏疾病

冠心病是诱发脑卒中的高危因素,合并有心脏病的人群,脑卒中发病率是健康人群的 3 倍以上^[2]。心房颤动与脑卒中发生关系密切,是诱发缺血性脑卒中的独立危险因素,约 50% 的心源性缺血性脑卒中是由心房颤动引起^[3-4]。高血压病是引起脑卒中最重要的独立危险因素,也是脑卒中不良预后的独立危险因素^[5-6]。高血压病与脑卒中再发密切相关^[7]。随着左心室重量的增加,高血压病患者脑卒中的发病率及病死率也成比例增加。研究发现收缩压对脑卒中的影响超过舒张压,随着年龄增加,血压的作用逐渐减弱,适当升高血压可降低老年人脑卒中的发病率^[8-10]。

2. 脑卒中与心功能不全

70 岁以上的脑卒中患者心功能不全的发病率可高达 50%^[11]。伴有心功能不全的脑卒中更易复发,且病死率更高。但心功能不全的临床症状常受患者的主观性影响,体征缺乏特异性,另外临床医师过度关注自己专科的疾病,而未能很好地识别心功能不全,导致未予及时诊断或治疗的情况很常见,有的甚至引起恶性后果。

3. 脑卒中与糖尿病

超过三分之二的慢性脑卒中患者和超过三分之一的急性脑卒中患者合并有高血糖症^[12]。美国一项研究显示,在所有年龄段,特别是小于 65 岁的人群,伴有糖尿病的患者脑卒中发病风险显著增加^[13]。当糖尿病病程超过 10 年时缺血性脑卒中发病风险增加 3 倍^[14]。高血糖对心血管系统的危害与多种直接和间接的通路加速动脉粥样硬化有关^[15]。虽然目前关于糖尿病及糖尿病前期与脑卒中的关系研究结论并不一致,但是糖尿病是脑卒中的独立危险因素还是得到公认的,糖尿病及糖尿病前期均为脑卒中不良结局的独立危险因素,两者均能增加脑卒中的发病风险^[16-20]。

4. 脑卒中与血脂代谢

血脂代谢异常与脑卒中的关系比较复杂。一般认为总胆固醇、甘油三酯、HDL-C、LDL-C 是缺血性脑卒中的危险因素^[21-22]。LDL-C 与绝经后女性脑卒中的发生密切相关^[23]。由于老年患者受长期的高血压病、糖尿病、血脂异常、吸烟等多种因素的影响,LDL-C 成为了老年人脑卒中的

重要危险因素。

二、脑卒中的心血管问题

脑卒中导致心、肺功能下降已获得共识,但其潜在的生理学机制并未获得系统的研究。研究显示 75% 脑卒中幸存者合并心脏病^[24]。对于无合并心血管疾病的初发脑卒中患者,同样存在心、肺功能下降的情况,除了可能因中枢神经系统损伤导致的中枢驱动能力下降外,还可能由于其它外周机制导致了心、肺功能的下降,其中包括骨骼肌萎缩、肌纤维表型的改变、偏瘫侧肢体血液供应的减少以及胰岛素抵抗^[25-29]。

1. 急性脑卒中的心血管损伤

关于急性脑卒中患者心功能改变的研究结果差别较大。一般认为急性脑卒中引起的心脏损害主要表现为心电图异常(AMI、心肌缺血、心律失常)、心内膜下出血或心力衰竭等^[30]。急性脑卒中患者心电图异常的发生率可高达 60%,约 6%~34% 患者出现血浆肌钙蛋白 I 和肌钙蛋白 T 浓度增加。

对于冠心病患者,急性脑卒中与冠心病在心肌损伤中可能起协同作用。美国成年人心血管风险评估指南建议所有无冠心病和脑卒中的成年人都应进行心血管风险评估,中国心血管病预防指南建议利用各种机会为患者进行心脑血管病风险评估^[31-32]。

2. 制动

脑卒中发生后,心血管系统与肌肉组织会发生一系列病理变化,血容量及左心室舒张末期容量减少 6%~11%,每搏量和心输出量降低 6%~13%^[33]。由于血容量下降,心功能减退,运动能力也随之减退。同时制动会导致肌肉萎缩和肌肉内脂肪含量增加,肌肉血液循环障碍,诸多因素共同作用对患者的恢复造成不利影响。

3. 运动模式异常的耗能增加

脑卒中患者普遍存在耐力减退,从事各种活动所消耗的能量较正常人明显增加。一项关于偏瘫患者的研究表明,与正常对照组相比,偏瘫步态的耗能较正常步态增加 55%~100%^[34-35]。这项研究还显示偏瘫患者难以自然维持其最有效的步行速度,提示耐力的减退反过来制约了运动功能的改善^[36-37]。

三、脑卒中的心血管功能评定

脑卒中患者心脏康复前应常规进行各项功能

评估,尤其是心功能评估。评估心功能应结合病史、症状、体征及辅助检查综合判断。常用的辅助检查包括:静息心电图、心脏彩色多普勒超声检查(彩超)、运动负荷心电图、心肺运动试验(CPET)、定距离测定(6 min 步行试验、10 m 步行试验)等。

CPET 通过测定人体在静息、运动及运动结束时每一次呼吸的氧摄取量、二氧化碳排出量和通气量,及心率、血压、心电图变化和患者运动时出现的症状,客观地评价循环呼吸功能和体力的废用性变化。CPET 主要参数有:最大运动负荷、峰值摄氧量(VO_{2max})、无氧阈、峰值耗氧量(VO_{2peak})、换气比值、心率、血压、心电图 ST 改变等^[38-43]。由于患侧肢体运动功能障碍,脑卒中偏瘫患者的 VO_{2max} 难以达到高平台,有学者通过平板步行负荷递增的方式评估了 131 例后遗症期偏瘫患者的 VO_{2peak} , 结果为 (13.6 ± 4) ml/(mg·min),而在年龄匹配,同样缺乏运动的健康对照组中,其 VO_{2peak} 可达到 25~30 ml/(mg·min),提示偏瘫患者的 VO_{2peak} 较健康人下降一半以上^[45-46]。临床实践中一般常用 VO_{2peak} 或无氧阈。其他的指标也常被用于临床研究中,如:①最大心搏数(HR_{max} , 220 - 年龄);② HR_{max} 时 VO_2 ;③ $VO_{2(100)}$ 或 $VO_{2(120)}$;④氧脉(每搏氧输送量);⑤氧负债;⑥生理耗能指数(PCI),等等。

脑卒中患者进行 CPET,可以明确心血管功能状态,判断心脏康复风险,同时能明确运动受限原因,准确评估运动能力,从而判断运动允许量,制定合理运动处方^[47-48]。还可获得心律变时性反应、运动血压和心率恢复等非心电图参数,越来越多的文献支持这些参数对患者预后判断的作用优于传统评价方式^[49-51]。

偏瘫患者常用的运动负荷试验方案分为递增负荷法和恒定负荷法。递增负荷法可选用的方式有:跑台、功率自行车、ShwinniAr-Dyne 能量测力计、上肢测力计、躯干前后屈运动、反复起立运动。跑台仅适用于步行能力接近于正常人的患者,功率自行车比跑台适应范围广,但不适用于躯干控制较差或存在下肢伸肌痉挛的患者。健侧上肢测力计可用于重度步行障碍者,且简单易行。在 VO_{2max} 测定困难的情况下可以通过躯干前后屈运动和反复起立运动来测定体力指标。

当无法开展 CPET 时,为了评价脑卒中患者的活动能力,6 min 步行试验是很好的选择,可反映受试者亚极量运动的能力^[52]。6 min 步行试验与 CPET 的最大运动能力存在相关性,可以用来预测受试者的 VO_{2max} ^[53]。

四、脑卒中患者的心血管康复

通常情况下,脑卒中康复是以改善患者运动功能、提高其日常生活活动能力为主要目标,重点在神经功能障碍的评估和治疗上^[54]。患者需要面对因为持续活动减少而引起的体力减退、活动能力下降而导致的慢性残疾以及心血管的功能障碍^[46]。

研究证明早期行心脏康复可显著提高患者的 VO_{2max} 和 6 min 步行试验距离,运动能力每增加 1 METs 可降低 12% 病死率^[43]。有学者观察了 20 例患者在接受现有的康复训练过程中物理疗法和作业疗法所引起的心血管应激水平,结果显示,每次治疗期间患者心率达到预定目标心率的时间极短,提示这些治疗所产生的心血管应激反应不足以产生训练效应。事实证明,现有的康复模式不能系统地提供充足的训练量来逆转患者体力的减退,也不能提供足够的重复性活动达到运动学习的最佳化,无法做到持续锻炼以保障脑卒中患者的健康。

针对脑卒中的心血管康复治疗,应根据患者肢体活动障碍情况选择徒手、踏车或手足联动踏车等;阻抗运动、柔韧性训练和平衡训练是必要的补充,但这些项目可能与神经康复训练项目存在重叠,应酌情减量。

五、脑卒中心血管康复的风险

脑卒中患者的心脏康复与单纯心脏病患者的心脏康复存在一定的区别,脑卒中大多数是在高血压病、冠心病、糖尿病、心房纤颤等基础上发生的,而且脑卒中后机体的各种病理生理变化也容易引发心血管并发症,这在相当程度上增加了脑卒中患者的治疗风险及康复治疗的复杂程度。一方面是疾病的隐匿性,脑卒中患者一般以神经系统症状为主诉入院,常常无心脏病的临床症状,是否合并心脏病常需进一步评估发现;另一方面,脑卒中患者亚极量负荷时的氧耗常高于正常人,达到疲劳时的 VO_{2max} 、负荷量、心率、收缩压均低于正常人。在急性脑卒中患者中,心律失常导致猝死的几率为 6%,且这种猝死的风

险持续约 1 个月。心律失常中心率增快与缺血性脑卒中后致残率及智能障碍有密切关系,可能预示着患者潜在的心血管病及高血压病的可能。

在进行心血管康复前,应结合心功能评估结果制定脑卒中患者的运动处方,强调个体化、被动训练与主动训练相结合,急性期及高危患者必须在心电、血压、血氧饱和度监护下进行。通过监测运动中的心率来确定训练强度,常根据运动负荷试验测得的最大心率来制定,即(最大心率-静息心率)×运动强度+静息心率。一般强度为 40%~80%,3~5 次/周,30~60 min/次。如无条件进行运动负荷试验的可在静息心率基础上增加 20~30 次/分,一般来说心率增加 20 次/分是较安全的。应结合运动前状态及运动中的表现、自我感知劳累程度评分(如 Borg 评分),实时适当调整运动方案,确保训练安全、有效。

六、展望

进行康复治疗脑卒中患者应尽早完善心血管功能评估,积极识别和处理心血管疾病。心血管康复训练不仅有利于改善脑卒中患者的运动能力,提高其生活质量,而且可以降低其心因性死亡风险及全因死亡风险,改善其远期预后。但有关脑卒中患者的心血管康复还面临以下几个问题:①脑卒中病程与运动功能分级对心血管康复的影响,脑卒中患者肢体功能的不同,尤其是下肢肌力、肌张力、平衡功能的差异会对患者有氧训练实际完成量和效果产生重要影响,康复治疗方案有待行大样本多中心的研究探讨;②脑卒中患者运动治疗与心血管康复的量效关系,不同训练方式、强度、时间和时程对脑卒中患者心血管效应的比较研究目前尚较少,需要加强研究;③缺乏残疾状态的脑卒中患者心血管康复研究,目前缺少在残疾状态下脑卒中患者进行心血管康复训练的研究,这个阶段的心血管康复训练不仅可以降低患者残疾程度,提高其日常生活活动能力,而且对脑卒中的二级预防有着积极意义,应该大力引导与推广;④需要进一步深入研究脑卒中中心血管康复的机制,目前关于脑卒中中心血管康复的机制研究很不充分,脑卒中患者心血管康复的分子生物学机制有待探讨,外周肌肉组织特性的改善对心脑血管疾病有无改善效应等等尚待进一步研究证实;⑤缺乏统一质量控制的培训,在 CPET 实施过程中,虽然增补了代谢模拟器,但

没有设立核心实验室对所有数据进行二次分析认证,各实验室用自己的 CPET 系统软件分析数据、报告结果,缺乏标准统一的规范化 CPET 操作及实验数据的分析与判读。建议进行多中心临床研究时,行 CPET 前必须由专门设立的核心实验室对实验室和系统进行质量认证。

参 考 文 献

- [1] 中华医学会心血管病学分会,中华心血管病杂志编辑委员会. 中国心血管病预防指南. 中华心血管病杂志, 2011, 39 (1): 3-22.
- [2] Okazaki S, Yoshioka D, Sakaguchi M, Sawa Y, Mochizuki H, Kitagawa K. Acute ischemic brain lesions in infective endocarditis: incidence, related factors, and postoperative outcome. *Cerebrovasc Dis*, 2013, 35 (2): 155-162.
- [3] Ratanakorn D, Keandoungchun J, Tegeler CH. Prevalence and association between risk factors, stroke subtypes, and abnormal ankle brachial index in acute ischemic stroke. *J Stroke Cerebrovasc Dis*, 2012, 21 (6): 498-503.
- [4] MacDougall NJ, Amarasinghe S, Muir KW. Secondary prevention of stroke. *Expert Rev Cardiovasc Ther*, 2009, 7 (9): 1103-1115.
- [5] Goldstein LB, Bushnell CD, Adams RJ, Appel LJ, Braun LT, Chaturvedi S, Creager MA, Culebras A, Eckel RH, Hart RG, Hinchey JA, Howard VJ, Jauch EC, Levine SR, Meschia JF, Moore WS, Nixon JV, Pearson TA; American Heart Association Stroke Council; Council on Cardiovascular Nursing; Council on Epidemiology and Prevention; Council for High Blood Pressure Research; Council on Peripheral Vascular Disease, and Interdisciplinary Council on Quality of Care and Outcomes Research. Guidelines for the primary prevention of stroke: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*, 2011, 42 (2): 517-584.
- [6] Blomstrand A, Blomstrand C, Ariai N, Bengtsson C, Björkelund C. Stroke incidence and association with risk factors in women: a 32-year follow-up of the Prospective Population Study of Women in Gothenburg. *BMJ Open*, 2014, 4 (10): e005173.
- [7] Kral M, Skoloudik D, Sanak D, Veverka T, Bartkova A, Dornak T, Hutyrá M, Vindis D, Ulehlova J, Slavik L, Svabova M, Kubickova V, Herzig R, Kanovsky P. Assessment of relationship between acute ischemic stroke and heart disease-protocol of a prospective observational trial. *Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub*, 2012, 156 (3): 284-289.
- [8] Hyun KK, Huxley RR, Arima H, Woo J, Lam TH, Ueshima H, Fang X, Peters SA, Jee SH, Giles GG, Barzi F, Woodward M. A comparative analysis of risk factors and stroke risk for Asian and non-Asian men: the Asia Pacific cohort studies collaboration. *Int J Stroke*, 2013, 8 (8): 606-611.
- [9] Vishram JK, Borglykke A, Andreassen AH, Jeppesen J, Ibsen H, Jørgensen T, Broda G, Palmieri L, Giampaoli S, Donfrancesco C, Kee F, Mancia G, Cesana G, Kuulasmaa K, Sans

- S, Olsen MH; MORGAM Project. Impact of age on the importance of systolic and diastolic blood pressures for stroke risk; the MONica, Risk, Genetics, Archiving, and Monograph (MORGAM) Project. *Hypertension*, 2012, 60 (5): 1117-1123.
- [10] Rothwell PM, Howard SC, Spence JD; Carotid Endarterectomy Trialists' Collaboration. Relationship between blood pressure and stroke risk in patients with symptomatic carotid occlusive disease. *Stroke*, 2003, 34 (11): 2583-2590.
- [11] Borlaug BA, Jaber WA, Ommen SR, Lam CS, Redfield MM, Nishimura RA. Diastolic relaxation and compliance reserve during dynamic exercise in heart failure with preserved ejection fraction. *Heart*, 2011, 97 (12): 964-969.
- [12] Hankey GJ, Anderson NE, Ting RD, Veillard AS, Romo M, Wosik M, Sullivan DR, O'Connell RL, Hunt D, Keech AC. Rates and predictors of risk of stroke and its subtypes in diabetes; a prospective observational study. *J Neurol Neurosurg Psychiatry*, 2013, 84 (3): 281-287.
- [13] Khoury JC, Kleindorfer D, Alwell K, Moomaw CJ, Woo D, Adeoye O, Flaherty ML, Khatri P, Ferioli S, Broderick JP, Kissela BM. Diabetes mellitus; a risk factor for ischemic stroke in a large biracial population. *Stroke*, 2013, 44 (6): 1500-1504.
- [14] Banerjee C, Moon YP, Paik MC, Rundek T, Mora-McLaughlin C, Vieira JR, Sacco RL, Elkind MS. Duration of diabetes and risk of ischemic stroke; the Northern Manhattan Study. *Stroke*, 2012, 43 (5): 1212-1217.
- [15] Zhang H, Dellsperger KC, Zhang C. The link between metabolic abnormalities and endothelial dysfunction in type 2 diabetes: an update. *Basic Res Cardiol*, 2012, 107 (1): 237.
- [16] Jia Q, Zhao X, Wang C, Wang Y, Yan Y, Li H, Zhong L, Liu L, Zheng H, Zhou Y, Wang Y. Diabetes and poor outcomes within 6 months after acute ischemic stroke; the China National Stroke Registry. *Stroke*, 2011, 42 (10): 2758-2762.
- [17] Lee M, Saver JL, Hong KS, Song S, Chang KH, Ovbiagele B. Effect of pre-diabetes on future risk of stroke; meta-analysis. *BMJ*, 2012, 344: e3564.
- [18] Wu S, Shi Y, Wang C, Jia Q, Zhang N, Zhao X, Liu G, Wang Y, Liu L, Wang Y; Investigators for the Survey on Abnormal Glucose Regulation in Patients With Acute Stroke Across China ACROSS-China. Glycated hemoglobin independently predicts stroke recurrence within one year after acute first-ever non-cardioembolic strokes onset in a Chinese cohort study. *PLoS One*, 2013, 8 (11): e80690.
- [19] Tanaka R, Ueno Y, Miyamoto N, Yamashiro K, Tanaka Y, Shimura H, Hattori N, Urabe T. Impact of diabetes and prediabetes on the short-term prognosis in patients with acute ischemic stroke. *J Neurol Sci*, 2013, 332 (1-2): 45-50.
- [20] Doi Y, Ninomiya T, Hata J, Fukuhara M, Yonemoto K, Iwase M, Iida M, Kiyohara Y. Impact of glucose tolerance status on development of ischemic stroke and coronary heart disease in a general Japanese population; the Hisayama study. *Stroke*, 2010, 41 (2): 203-209.
- [21] Wu Y, Liu X, Li X, Li Y, Zhao L, Chen Z, Li Y, Rao X, Zhou B, Detrano R, Liu K; USA-PRC Collaborative Study of Cardiovascular and Cardiopulmonary Epidemiology Research Group; China Multicenter Collaborative Study of Cardiovascular Epidemiology Research Group. Estimation of 10-year risk of fatal and nonfatal ischemic cardiovascular diseases in Chinese adults. *Circulation*, 2006, 114 (21): 2217-2125.
- [22] Varbo A, Nordestgaard BG, Tybjaerg-Hansen A, Schnohr P, Jensen GB, Benn M. Nonfasting triglycerides, cholesterol, and ischemic stroke in the general population. *Ann Neurol*, 2011, 69 (4): 628-634.
- [23] Berger JS, McGinn AP, Howard BV, Kuller L, Manson JE, Ottavos J, Curb JD, Eaton CB, Kaplan RC, Lynch JK, Rosenbaum DM, Wassertheil-Smoller S. Lipid and lipoprotein biomarkers and the risk of ischemic stroke in postmenopausal women. *Stroke*, 2012, 43 (4): 958-966.
- [24] Roth EJ. Heart disease in patients with stroke. Part II: Impact and implications for rehabilitation. *Arch Phys Med Rehabil*, 1994, 75 (1): 94-101.
- [25] Ivey FM, Hafer-Macko CE, Macko RF. Exercise rehabilitation after stroke. *NeuroRx*, 2006, 3 (4): 439-450.
- [26] Ryan AS, Dobrovolsky CL, Smith GV, Silver KH, Macko RF. Hemiparetic muscle atrophy and increased intramuscular fat in stroke patients. *Arch Phys Med Rehabil*, 2002, 83 (12): 1703-1707.
- [27] De Deyne PG, Hafer-Macko CE, Ivey FM, Ryan AS, Macko RF. Muscle molecular phenotype after stroke is associated with gait speed. *Muscle Nerve*, 2004, 30 (2): 209-215.
- [28] Billinger SA, Matilage AE, Ashenden AL, Lentz AA, Harter G, Rippee MA. Aerobic exercise in subacute stroke improves cardiovascular health and physical performance. *J Neurol Phys Ther*, 2012, 36 (4): 159-165.
- [29] Kernan WN, Inzucchi SE, Viscoli CM, Brass LM, Bravata DM, Shulman GI, McVeety JC, Horwitz RI. Impaired insulin sensitivity among nondiabetic patients with a recent TIA or ischemic stroke. *Neurology*, 2003, 60 (9): 1447-1451.
- [30] van der Bilt IA, Hasan D, Vandertop WP, Wilde AA, Algra A, Visser FC, Rinkel GJ. Impact of cardiac complications on outcome after aneurysmal subarachnoid hemorrhage: a meta-analysis. *Neurology*, 2009, 72 (7): 635-642.
- [31] Greenland P, Alpert JS, Beller GA, Benjamin EJ, Budoff MJ, Fayad ZA, Foster E, Hlatky MA, Hodgson JM, Kushner FG, Lauer MS, Shaw LJ, Smith SC Jr, Taylor AJ, Weintraub WS, Wenger NK, Jacobs AK, Smith SC Jr, Anderson JL, Albert N, Buller CE, Creager MA, Ettinger SM, Guyton RA, Halperin JL, Hochman JS, Kushner FG, Nishimura R, Ohman EM, Page RL, Stevenson WG, Tarkington LG, Yancy CW; American College of Cardiology Foundation; American Heart Association. 2010 ACCF/AHA guideline for assessment of cardiovascular risk in asymptomatic adults: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol*, 2010, 56 (25): e103-e103.

- [32] Anderson KM, Wilson PW, Odell PM, Kannel WB. An updated coronary risk profile. A statement for health professionals. *Circulation*, 1991, 83 (1): 356-362.
- [33] Bleeker MW, De Groot PC, Rongen GA, Rittweger J, Felsenberg D, Smits P, Hopman MT. Vascular adaptation to deconditioning and the effect of an exercise countermeasure: results of the Berlin Bed Rest study. *J Appl Physiol* (1985), 2005, 99 (4): 1293-300.
- [34] Corcoran PJ, Jebsen RH, Brengelmann GL, Simons BC. Effects of plastic and metal leg braces on speed and energy cost of hemiparetic ambulation. *Arch Phys Med Rehabil*, 1970, 51 (2): 69-77.
- [35] Gersten JW, Orr W. External work of walking in hemiparetic patients. *Scand J Rehabil Med*, 1971, 3 (1): 85-88.
- [36] Fisher SV, Gullickson G Jr. Energy cost of ambulation in health and disability: a literature review. *Arch Phys Med Rehabil*, 1978, 59 (3): 124-133.
- [37] Olney SJ, Monga TN, Costigan PA. Mechanical energy of walking of stroke patients. *Arch Phys Med Rehabil*, 1986, 67 (2): 92-98.
- [38] Myers J, Arena R, Franklin B, Pina I, Kraus WE, McInnis K, Balady GJ; American Heart Association Committee on Exercise, Cardiac Rehabilitation, and Prevention of the Council on Clinical Cardiology, the Council on Nutrition, Physical Activity, and Metabolism, and the Council on Cardiovascular Nursing. Recommendations for clinical exercise laboratories: a scientific statement from the American heart association. *Circulation*, 2009, 119 (24): 3144-3161.
- [39] Prakash M, Myers J, Froelicher VF, Marcus R, Do D, Kalisetti D, Atwood JE. Clinical and exercise test predictors of all-cause mortality: results from > 6,000 consecutive referred male patients. *Chest*, 2001, 120 (3): 1003-1013.
- [40] Myers J, Prakash M, Froelicher V, Do D, Partington S, Atwood JE. Exercise capacity and mortality among men referred for exercise testing. *N Engl J Med*, 2002, 346 (11): 793-801.
- [41] Ghayoumi A, Raxwal V, Cho S, Myers J, Chun S, Froelicher VF. Prognostic value of exercise tests in male veterans with chronic coronary artery disease. *J Cardiopulm Rehabil*, 2002, 22 (6): 399-407.
- [42] Kokkinos P, Myers J, Kokkinos JP, Pittaras A, Narayan P, Manolis A, Karasik P, Greenberg M, Papademetriou V, Singh S. Exercise capacity and mortality in black and white men. *Circulation*, 2008, 117 (5): 614-622.
- [43] Kodama S, Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, Sugawara A, Totsuka K, Shimano H, Ohashi Y, Yamada N, Sone H. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA*, 2009, 301 (19): 2024-2035.
- [44] Ivey FM, Macko RF, Ryan AS, Hafer-Macko CE. Cardiovascular health and fitness after stroke. *Top Stroke Rehabil*, 2005, 12 (1): 1-16.
- [45] Ivey FM, Hafer-Macko CE, Macko RF. Exercise rehabilitation after stroke. *Neuro Rx*, 2006, 3 (4): 439-450.
- [46] Bruce RA, Kusumi F, Hosmer D. Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. *Am Heart J*, 1973, 85 (4): 546-562.
- [47] 谭晓越, 孙兴国. 从心肺运动的应用价值看医学整体整合的需求. *医学与哲学: 人文社会医学版*, 2013, 34 (3): 28-31.
- [48] Wassermann K, Hansen JE, Sue DY, Whipp BJ. Principles of exercise testing and interpretation. 5th ed. Philadelphia: Lippincott Williams & Wilkins, 2011: 194-234.
- [49] Stavropoulos-Kalinoglou A, Metsios GS, Veldhuijzen van Zanten JJ, Nightingale P, Kitas GD, Koutedakis Y. Individualised aerobic and resistance exercise training improves cardiorespiratory fitness and reduces cardiovascular risk in patients with rheumatoid arthritis. *Ann Rheum Dis*, 2013, 72 (11): 1819-1825.
- [50] Pedersen JØ, Zimmermann E, Stallknecht BM, Bruun JM, Kroustrup JP, Larsen JF, Helge JW. Lifestyle intervention in the treatment of severe obesity. *Ugeskr Laeger*, 2006, 168 (2): 167-172.
- [51] Fleg JL, Morrell CH, Bos AG, Brant LJ, Talbot LA, Wright JG, Lakatta EG. Accelerated longitudinal decline of aerobic capacity in healthy older adults. *Circulation*, 2005, 112 (5): 674-682.
- [52] Aboyans V, Criqui MH, Abraham P, Allison MA, Creager MA, Diehm C, Fowkes FG, Hiatt WR, Jönsson B, Lacroix P, Marin B, McDermott MM, Norgren L, Pande RL, Preux PM, Stoffers HE, Treat-Jacobson D; American Heart Association Council on Peripheral Vascular Disease; Council on Epidemiology and Prevention; Council on Clinical Cardiology; Council on Cardiovascular Nursing; Council on Cardiovascular Radiology and Intervention, and Council on Cardiovascular Surgery and Anesthesia. Measurement and interpretation of the ankle-brachial index: a scientific statement from the American Heart Association. *Circulation*, 2012, 126 (24): 2890-2909.
- [53] Slaman J, Dallmeijer A, Stam H, Russchen H, Roebroek M, van den Berg-Emons R; Learn2Move Research Group. The six-minute walk test cannot predict peak cardiopulmonary fitness in ambulatory adolescents and young adults with cerebral palsy. *Arch Phys Med Rehabil*, 2013, 94 (11): 2227-2233.
- [54] Macko RF, Ivey FM, Forrester LW. Task-oriented aerobic exercise in chronic hemiparetic stroke: training protocols and treatment effects. *Top Stroke Rehabil*, 2005, 12 (1): 45-57.

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