步态诱发功能性电刺激联合减重平板训练治疗痉挛型脑性瘫痪儿童临床研究

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收稿日期：2023-05-25；接受日期：2023-08-22
基金项目：上海市虹口区卫生健康委员会中医药科研课题青年项目（HKGYQY-ZY-2023-24）；
同济大学附属上海第四人民医院科研启动专项基金（sykyqd02001）
DOI：10.3724/SP.J.1329.2023.06005
开放科学（资源服务）标识码（OSID）：

摘要 **目的：**探讨步态诱发功能性电刺激（FES）联合减重平板训练（BWSTT）对痉挛型脑性瘫痪（SCP）儿童粗大运动功能和步行功能的影响。**方法：**选择2022年3月—2023年3月在同济大学附属上海市第四人民医院就诊的SCP儿童60例，采用SAS软件随机数字模块产生随机序列分为对照组、减重平板训练组和联合干预组，每组20例。对照组接受常规康复训练，1次/d，40 min/次，5 d/周，共训练8周。减重平板训练组在对照组基础上接受BWSTT，平板坡度0°，初始速度0.09 m/s，以0.03 m/s增量逐渐调整至患儿可承受的适宜速度，初始减重为患儿体质量的30%，逐渐调整至完全支撑患儿自身体质量为宜。联合干预组在减重平板训练组基础上接受步态诱发FES，使用低频电子脉冲刺激仪刺激患儿的腓总神经和胫前肌，刺激强度以出现踝背伸和外翻的理想动作且患儿能够耐受为宜。2组均训练1次/d，20 min/次，5 d/周，共8周。分别于治疗前后采用粗大运动功能评定量表88项（GMFM-88）D区（站立）和E区（走跑跳）评估患儿粗大运动功能；采用六分钟步行试验（6MWT）评估患儿步行功能；采用生理消耗指数（PCI）评估患儿的步行效率；分析患儿跨步长、步宽和步速等步态参数。**结果：**与治疗前比较，3组治疗后GMFM-D、GMFM-E评分，6MWT，跨步长和步速均明显升高，PCI、步宽均明显降低，差异具有统计学意义（$P<0.05$）。与对照组比较，减重平板训练组和联合干预组治疗后GMFM-D、GMFM-E评分，6MWT，跨步长和步速均明显更高，PCI、步宽均明显更低，差异具有统计学意义（$P<0.05$）。与减重平板训练组比较，联合干预组治疗后GMFM-D、GMFM-E评分，6MWT，跨步长和步速均明显更高，PCI、步宽均明显更低，差异具有统计学意义（$P<0.05$）。**结论：**步态诱发FES联合BWSTT能改善SCP儿童运动功能，纠正异常步态，提高步行效率，值得在临床推广。

关键词 痉挛型脑性瘫痪；步态诱发功能性电刺激；减重平板训练；步行功能；步态分析

痉挛型脑性瘫痪（spastic cerebral palsy，SCP）是最常见的脑性瘫痪（cerebral palsy，CP）类型，约占所有CP患儿的60%～70%[1]。SCP常因双下肢痉挛和肌肉力量不协调而出现屈髋、屈膝、足下垂等症状，临床表现为剪刀步态、蹲伏步态等，患儿步行时速度下降，步长缩短且身体能量消耗大，从而影响患儿正常步态模式的建立，降低步行功能[2-3]。常规康复治疗手段（包括肌力训练、关节活动度训练和步态纠正训练等）虽能不同程度改善SCP儿童的步行功能[4]，但训练周期相对较长，且由于患儿肌力不足或下肢痉挛等原因不能长时间、有效地进行步行训练，影响康复效果。步态诱发功能性电刺激（func-

引用格式：宋薇，钟跃，柯晓华，等. 步态诱发功能性电刺激联合减重平板训练治疗痉挛型脑性瘫痪儿童临床研究[J]. 康复学报，2023，33(6)：508-514.
SONG W，ZHONG Y，KE X H，et al. Rehabilitation efficacy of gait induced functional electrical stimulation combined with body-weight supported treadmill training on children with spastic cerebral palsy [J]. Rehabil Med，2023，33(6)：508-514.
DOI：10.3724/SP.J.1329.2023.06005

tional electrical stimulation，FES）是通过步态传感器检测到胫骨倾斜角的变化情况来控制低频脉冲电流刺激目标肌肉，诱发肌肉收缩来模拟完成正常的步行运动以产生即时效应，直接改善步行功能[5-6]；减重平板训练（body-weight supported treadmill training，BWSTT）利用悬吊装置不同程度地减轻患儿体质量对其下肢的负荷，在步行平板上进行周期性步行训练来改善患儿的步行功能[7]。SCP儿童肌张力异常，下肢负重能力差而导致步行时的姿势异常，步行效率降低。BWSTT通过减重帮助患儿下肢得到合适的负重量，减少其步行耗能，提高步行效率；在缓慢、有控制的运动过程中可以抑制肌张力异常增大，牵拉痉挛肌群，有利于纠正患儿异常步态。此外，减重设备的保护使患儿处于一种被保护状态，可有效增加其行走时的信心[8]。但是BWSTT并不能完全消除患儿本身肌肉功能的不足，对患儿足下垂、足内翻和尖足等疗效有限，联合使用FES通过诱发肌肉运动产生即时效应可替代或矫正肌肉已丧失的功能，可能会产生协同效应[9]。

1　临床资料

1.1　病例选择标准

1.1.1　诊断标准　符合2022年《中国脑性瘫痪康复治疗指南》有关脑性瘫痪的诊断标准[10]。

1.1.2　纳入标准　① 粗大运动功能分级（gross motor function classification system，GMFCS）为Ⅰ～Ⅱ级；② 学龄期儿童，年龄6～14岁；③ 能理解简单指令；④ 本研究前6个月内未接受过肉毒素治疗；⑤ 既往未接受过跟腱延长术、选择性脊神经后根切断术和下肢矫形术等外科手术。

1.1.3　排除标准　① 患有感染、外伤或因遗传代谢性疾病等造成运动功能障碍或存在严重癫痫者；② 伴严重关节畸形、肌肉僵硬等器质性病变；③ 近期服用过缓解肌张力的药物；④ 合并有严重心、肝、肾等脏器功能不全者；⑤ 不能独立行走6 min以上。

1.1.4　中止和脱落标准　① 患儿依从性差，疗程中不能坚持治疗或自行更改治疗方案；② 治疗期间出现严重不良反应或并发症、合并症，不宜继续接受治疗者；③ 观察资料不全而影响评估者。

1.2　一般资料

选择2022年3月—2023年3月在同济大学附属上海市第四人民医院就诊的SCP儿童60例，由1名对本研究分组设计不知情人员采用SAS软件的随机数字模块产生随机序列，用顺序编号且不透光的信封进行分配隐藏，将患儿分为对照组、减重平板训练组和联合干预组，每组20例。3组性别、年龄、身高、体质量和GMFCS分级比较，差异均无统计学意义，具有可比性。见表1。

表1　3组一般资料比较

Table1　Comparison of general data in three groups

组别	例数	性别		年龄/($\bar{x}\pm s$，岁)	身高/($\bar{x}\pm s$，cm)	体质量/($\bar{x}\pm s$，kg)	GMFCS分级	
		男	女				Ⅰ级	Ⅱ级
对照组	20	11	9	8.60±1.39	139.15±6.92	24.70±2.39	9	11
减重平板训练组	20	13	7	8.75±1.21	140.60±4.25	24.00±1.66	5	15
联合干预组	20	8	12	8.40±1.54	137.35±6.18	25.31±2.22	10	10
χ^2/F值		2.545		0.563	1.528	1.924	2.917	
P值		0.280		0.755	0.226	0.155	0.233	

2　方　法

2.1　治疗方法

2.1.1　对照组　接受常规康复训练。以Bobath、Rood等神经发育学疗法为主，内容包括关节被动活动、手法牵伸降低肌张力，改善关节活动度；诱发髋、膝、踝关节主动活动和肌肉力量训练；躯干控制训练、重心转移训练和步行训练增强步行能力，1次/d，40 min/次，5 d/周，共训练8周。

2.1.2　减重平板训练组　在对照组基础上接受BWSTT。应用减重平板步行训练仪（苏州好博医疗器械股份有限公司，型号：HB-JZB-2）进行BWSTT。具体方法如下：① 在患儿的腋部固定好悬吊带；② 向患者说明此次训练的目的、意义及需要配合的事项；③ 检查仪器和悬吊带是否处于正常状态；④ 训练前先让患儿保持直立状态2～3 min，以适应体位；⑤ 平板坡度0°，初始速度0.09 m/s，并以0.03 m/s增量逐渐调整至患儿可承受的适宜速度。初始减重以患儿体质量的30%，逐渐调整至患儿髋关节能伸展、下肢能完全支撑自身体质量为宜；⑥ 治疗师在患儿旁指导并纠正患儿的异常步态及

异常姿势。

注意事项：为确保患儿训练安全性，1名治疗师站于患儿身后，辅助躯干和骨盆旋转以帮助患儿完成重心转移；另1名治疗师辅助患儿进行正常步行训练[11]。训练过程中患儿自觉疲劳程度（rating of perceived exertion，RPE）评分＞5分应即可停止训练并休息，直至RPE评分＜5分方可继续训练[12]。1次/d，20 min/次，5 d/周，共训练8周。

2.1.3 联合干预组 在减重平板训练组基础上接受步态诱发FES。使用低频电子脉冲刺激仪（深圳讯丰通医疗股份有限公司，型号：XFT-2001型）进行FES。具体方法如下：① 患儿坐位，下肢稍展开，双侧膝关节轻微弯曲；② 将电极片贴于患儿双下肢胫前肌肌腹和腓总神经处；③ 设置合理的刺激参数，刺激强度以出现踝背伸和外翻的理想动作且患儿能够耐受为宜；④ 设定患儿"起步角度"（健侧下肢负重时，患足脚尖着地、脚跟抬起时胫骨倾斜的角度）和"落地角度"（健侧下肢负重时，患足下肢离地到脚跟着地时胫骨倾斜的角度）；⑤ 设置完毕后让患儿步行，观察踝背伸情况，若踝背伸动作不明显需及时调整电极位置和电流强度[13]。1次/d，20 min/次，5 d/周，共训练8周。

2.2 观察指标

分别于治疗前后由同1位对分组不知情、受过专业培训的治疗师进行以下指标评估。

2.2.1 粗大运动功能 采用粗大运动功能评定量表88项（gross motor function measure 88，GMFM-88）D区（站立）和E区（走跑跳）评估患儿粗大运动功能[14]。每个项目根据患儿完成的程度分为4级，分别赋予0～3分，0分为最差，3分表示完成度最好。统计每个区的各个项目得分数，累加作为该区的总分。

2.2.2 步行功能 采用六分钟步行试验（six-minute walking test，6MWT）评估患儿步行功能。在6 min内患儿所行走的最大距离为患儿步行距离，并计算步行速度。此外，分别在测试前后测量患儿脉率（持续1 min），包括静止心率和运动心率，计算生理消耗指数（physiological cost index，PCI）以评估患儿的步行效率[15-16]。

PCI＝（运动心率－静止心率）/步行速度

2.2.3 步态分析 采用高速摄像机和数字图像处理软件Peak Motus 9.0进行步态分析[17]。测试过程如下：在宽敞明亮的房间，步道为木质地板，室温在20～25 ℃，嘱患儿以自然步态走过标准线（长2 m，宽20 cm），高速摄像机拍摄患儿的侧面和背面。拍摄结束后选取图像质量好、步态接近日常习惯的图像，提取图像中包含整个步态周期的关键画面（包括足跟开始着地、对侧下肢着地和足跟再次着地等），并根据关键画面内地面标准线的比例和视频时间节点计算出患儿跨步长（一侧足跟着地到该侧足跟再次着地时的距离）、步宽（左右两侧足跟中点投射点间的横向距离）和步速（步行时每秒走过的距离）。

2.3 统计学方法

采用SPSS 23.0统计软件进行数据分析。计量资料服从正态分布采用（$\bar{x}\pm s$）表示，组内治疗前后比较采用配对样本t检验，组间比较采用单因素方差分析，方差齐两两比较采用LSD-t检验；计数资料采用χ^2检验。P＜0.05为差异具有统计学意义。

3 结 果

3.1 3组治疗前后GMFM-D、GMFM-E评分比较

与治疗前比较，3组治疗后GMFM-D、GMFM-E评分均明显升高，差异具有统计学意义（P＜0.05）。与对照组比较，减重平板训练组和联合干预组治疗后GMFM-D、GMFM-E评分均明显升高，差异具有统计学意义（P＜0.05）。与减重平板训练组比较，联合干预组治疗后GMFM-D、GMFM-E评分均明显升高，差异具有统计学意义（P＜0.05）。见表2。

表2 3组治疗前后GMFM-D和GMFM-E评分比较（$\bar{x}\pm s$） 分

Table 2 Comparison of GMFM-D and GMFM-E scores in three groups before and after treatment ($\bar{x}\pm s$) Scores

组别	例数	时间	GMFM-D评分	GMFM-E评分
对照组	20	治疗前	22.20±1.94	31.95±2.37
		治疗后	27.20±1.40 1)	36.30±1.59 1)
减重平板训练组	20	治疗前	21.20±1.58	31.70±1.42
		治疗后	30.75±2.38 1)2)	40.10±2.31 1)2)
联合干预组	20	治疗前	21.65±1.57	31.05±2.16
		治疗后	33.70±2.05 1)2)3)	44.75±1.68 1)2)3)

注：与治疗前比较，1）P＜0.05；与对照组比较，2）P＜0.05；与减重平板训练组比较，3）P＜0.05。

Note: Compared with that before treatment, 1) P<0.05; compared with the control group, 2) P<0.05; compared with the BWSTT group, 3) P<0.05.

3.2　3组治疗前后6MWT和PCI比较

与治疗前比较,3组治疗后6MWT均明显升高,PCI均明显降低,差异具有统计学意义($P<0.05$)。与对照组比较,减重平板训练组和联合干预组治疗后6MWT均明显更高,PCI均明显更低,差异具有统计学意义($P<0.05$)。与减重平板训练组比较,联合干预组治疗后6MWT均明显更高,PCI明显更低,差异具有统计学意义($P<0.05$)。见表3。

3.3　3组治疗前后步态参数比较

与治疗前比较,3组治疗后跨步长和步速均明显升高,步宽均明显降低,差异均有统计学意义($P<0.05$)。与对照组比较,减重平板训练组和联合干预组治疗后跨步长和步速均明显更高,步宽均明显更低,差异具有统计学意义($P<0.05$)。与减重平板训练组比较,联合干预组治疗后跨步长和步速均明显更高,步宽明显更低,差异具有统计学意义($P<0.05$)。见表4。

表3　3组治疗前后6MWT和PCI比较($\bar{x}\pm s$)　分

Table 3　Comparison of 6MWT and PCI in three groups before and after treatment ($\bar{x}\pm s$)　Scores

组别	例数	时间	6MWT/m	PCI/(beats/m)
对照组	20	治疗前	130.69±5.22	0.62±0.04
		治疗后	146.10±5.09 1)	0.55±0.05 1)
减重平板训练组	20	治疗前	131.26±5.38	0.61±0.05
		治疗后	157.61±4.84 1)2)	0.48±0.04 1)2)
联合干预组	20	治疗前	129.47±6.99	0.60±0.05
		治疗后	165.57±5.84 1)2)3)	0.41±0.03 1)2)3)

注:与治疗前比较,1) $P<0.05$;与对照组比较,2) $P<0.05$;与减重平板训练组比较,3) $P<0.05$。

Note: Compared with that before treatment, 1) $P<0.05$; compared with the control group, 2) $P<0.05$; compared with the BWSTT group, 3) $P<0.05$.

表4　3组治疗前后步态参数比较($\bar{x}\pm s$)

Table 4　Comparison of gait data in three groups before and after treatment ($\bar{x}\pm s$)

组别	例数	时间	跨步长/m	步宽/m	步速/(m/s)
对照组	20	治疗前	0.32±0.03	0.21±0.03	0.45±0.03
		治疗后	0.39±0.04 1)	0.19±0.02 1)	0.49±0.03 1)
减重平板训练组	20	治疗前	0.33±0.03	0.22±0.02	0.46±0.02
		治疗后	0.42±0.05 1) 2)	0.17±0.01 1)2)	0.53±0.05 1)2)
联合干预组	20	治疗前	0.31±0.03	0.21±0.03	0.46±0.03
		治疗后	0.47±0.05 1)2)3)	0.15±0.02 1)2)3)	0.60±0.04 1)2)3)

注:与治疗前比较,1) $P<0.05$;与对照组比较,2) $P<0.05$;与减重平板训练组比较,3) $P<0.05$。

Note: Compared with that before treatment, 1) $P<0.05$; compared with the control group, 2) $P<0.05$; compared with the BWSTT group, 3) $P<0.05$.

4　讨　论

4.1　步态诱发FES联合BWSTT可以改善SCP儿童步行功能

本研究结果显示,与对照组、减重平板训练组比较,联合干预组治疗后GMFM-D、GMFM-E评分和6MWT均明显升高,PCI明显降低,提示步态诱发FES联合BWSTT可有效改善SCP儿童步行功能。① BWSTT可改善SCP儿童下肢负重程度,提高步行效率:SCP儿童因中枢神经系统受损,常表现为双下肢痉挛或肌肉力量不足[18],负重能力较差。传统的牵伸、肌力训练和运动控制等康复训练多注重纠正肢体较高的肌张力和异常姿势,常忽视CP儿童下肢负重能力的训练[19]。BWSTT可不同程度地减轻患儿自身体质量对下肢的负荷,在治疗师的管理下通过稳定躯干平衡和有效重心转移等方法,配合电动活动平板带动患儿产生重复和节律性的步行模式,使支撑能力不足的患儿可以尽早进行步行功能训练[20]。BWSTT通过减重使患儿髋关节完全伸展、下肢能完全支撑自身体质量,使患儿步行时身体重心趋于对称,以便在早期使患儿下肢得到合适的负重,并减少其步行时的耗能,提高步行效率。这与张琦等[12]研究结果显示BWSTT可明显改善CP儿童步行能力和步行效率,从而提高其功能性步行分级的结果一致。② FES联合BWSTT可帮助SCP患儿有效激活运动皮层并促使皮质建立兴奋痕迹,改善步行功能:FES属于神经肌肉电刺激范畴。通过预先设定的程序,FES利用低频脉冲电流刺激已失去功能但仍具有神经支配功能的肌肉,诱发肌肉运动以产生即时效应来替代或矫正肌肉已丧失的功能[9]。FES通过步态传感器检测患儿步态情况,适

时精确控制低频电脉冲刺激腓总神经,促进胫前肌和腓骨肌收缩以控制SCP儿童足外翻和背屈动作,以诱发其在步行中已丧失的踝关节功能。YAN等[21]研究发现,步行时结合FES治疗更接近于患者实际步行情况,可更有效改善患者步行功能,特别是步行中的踝背伸功能而非单纯的踝背伸功能。步态诱发FES在摆动相时,使SCP儿童胫前肌收缩促使踝背屈和踝外翻,有利于摆动相足廓清,降低步行时能量消耗;同时能不断重复刺激已丧失功能的肌肉重新活动,加强运动和感觉信息输入,有助于神经系统建立正确的皮质兴奋痕迹。BWSTT可不同程度地减轻患儿自身体质量对下肢的负荷,有利于摆动相足廓清及降低步行时能量消耗;BWSTT通过电动活动平板带动患儿产生重复和节律性的步态,输入正确的步行运动感觉,能有效激活运动皮层并促使皮质建立兴奋痕迹,从而改善步行功能。这与范艳萍等[22]研究结果一致。

4.2　步态诱发FES联合BWSTT治疗可以改善SCP儿童的步态

本研究结果显示,与对照组、减重平板训练组比较,联合干预组治疗后跨步长和步速均明显升高,步宽明显降低,提示步态诱发FES联合BWSTT可以改善SCP儿童步态。可能与以下原因有关:SCP患儿负重能力较差,下肢肌张力和肌力异常导致步行时常会出现尖足步态或剪刀步态[23]。研究表明SCP儿童跨步长和步速明显低于正常儿童,步宽、步行能量消耗明显高于正常儿童[24]。BWSTT根据神经易化技术理念,以缓慢、有控制的运动抑制肌张力,根据患儿步行能力设置合理的平板速度,通过传送带的匀速带动,在支撑末期使患儿髋关节屈肌和腓肠肌得到牵拉,促使下肢向前摆动和改善踝关节活动度,有利于纠正尖足或剪刀步态[8]。BWSTT虽能辅助SCP儿童顺利完成屈膝、提足、落地等步行动作,使其步态更加稳健、自然和轻松,但对于患儿因胫前肌和腓骨肌无力所致足下垂、足内翻和尖足等情况的疗效有限。因此,本研究联合使用步态诱发FES可有效弥补这一缺陷。步态诱发FES在支撑相时刺激腓总神经,促使胫前肌收缩,产生交互作用抑制腓肠肌痉挛,改善足内翻和足下垂,提高踝关节的功能性运动,从而改善SCP儿童异常步态。这2种方法的有机结合,能在有限训练时间内起到协同作用,进一步提升康复疗效。

5　小　结

步态诱发FES联合BWSTT可以改善SCP儿童步行能力和步态,值得临床推广与应用。但本研究仍存在样本量相对较少且缺乏长期随访观察等不足之处,今后仍需开展大样本临床随机对照研究,加强出院后随访,以进一步验证步态诱发FES联合BWSTT治疗SCP儿童的疗效。

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Rehabilitation Efficacy of Gait Induced Functional Electrical Stimulation Combined with Body-Weight Supported Treadmill Training on Children with Spastic Cerebral Palsy

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ABSTRACT **Objective:** To observe the effect of gait induced functional electrical stimulation (FES) combined with body-weight supported treadmill training (BWSTT) on gross motor function and walking function of children with spastic cerebral palsy (SCP). **Methods:** A total of 60 children with spastic cerebral palsy in the Shanghai Fourth People's Hospital Affiliated to Tongji University from March 2022 to March 2023 were randomly divided into control group, BWSTT group and combined intervention group according to a randomized sequence by SAS software, with 20 cases in each group. The control group received conventional rehabilitation therapy, once a day, 40 minutes a time, five days a week, lasting for eight weeks. The BWSTT group received body-weight supported treadmill training in addition to the training of the control group. The slope of the plate was 0°, the initial speed was 0.09 m/s, and the increment of 0.03 m/s was gradually adjusted to the appropriate speed that the child could walk with. The initial weight support was 30% of the child's body mass, and it was gradually adjusted to fully support the child's own body mass. The combined intervention group received gait induced FES in addition to the training of the BWSTT group. A low-frequency electronic pulse stimulator was used to stimulate the common peroneal nerve and anterior tibialis muscle of the children, and the stimulation intensity was set at the desirable movements of ankle dorsiflexion and valgus, and could be tolerated by the children, once a day, 20 minutes a time, five days a week, lasting for eight weeks. Before and after treatment, D (standing) and E (walking, running and jumping) zones of the 88-item gross motor function measurement 88 (GMFM-88) was used to assess the children's gross motor function; six-minute walking test (6MWT) was used to assess walking function; physiological expenditure index (PCI) was used to evaluate walking efficiency; and gait parameters of the children (such as stride length, stride width and stride speed) were analyzed. **Results:** Compared with that before treatment, GMFM-D and GMFM-E scores, 6MWT, stride length and stride speed were significantly higher and PCI and stride width were significantly lower in the three groups after treatment, and the differences were statistically significant (P<0.05). Compared with the control group, GMFM-D and GMFM-E scores, 6MWT, stride length and stride speed were significantly higher, and PCI and stride width were significantly lower in the BWSTT group and the combined intervention group after treatment, and the differences were statistically significant (P<0.05). Compared with the BWSTT group, the GMFM-D, GMFM-E scores, 6MWT, stride length and stride speed were significantly higher, and PCI and stride width were significantly lower in the combined intervention group after treatment, and the differences were statistically significant (P<0.05). **Conclusion:** Gait-induced FES combined with BWSTT can improve motor function, correct abnormal gait, and improve walking efficiency in children with SCP, which is recommended for clinical application.

KEY WORDS spastic cerebral palsy; gait-induced functional electrical stimulation; body-weight supported treadmill training; walking function; gait analysis
DOI:10.3724/SP.J.1329.2023.06005

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Effect of Contralaterally Controlled Neuromuscular Electrical Stimulation on Brain Function Connectivity of Patients with Hemiplegia after Stroke

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ABSTRACT **Objective:** To explore the effect of contralaterally controlled neuromuscular electrical stimulation (CCNMES) on brain functional connectivity of hemiplegic patients after stroke by functional near-infrared spectroscopy (fNIRS). **Methods:** A total of 48 stroke patients with upper limb hemiplegia in the Rehabilitation Medical Center of Changzhou De'an Hospital from July 2021 to January 2022 were recruited and randomly divided into control group and observation group according to the computer-generated randomization list, with 24 cases in each group. The control group received neuromuscular electrical stimulation (NMES). Two stimulating electrodes were placed on the extensor side of the affected forearm to produce wrist extension, and the stimulation intensity was set at a level that could produce maximum wrist extension without causing discomfort to the patient, with a rectangular pulse of 60 Hz, a pulse width of 200 µs, and a stimulation period of 15 s on and 10 s off. The observation group received CCNMES with two surface electrodes and one reference electrode placed on the extensor side of the healthy forearm, and two stimulating electrodes placed on the extensor side of the affected forearm to generate wrist extension. The intensity of stimulation on the affected wrist was set that the affected wrist could be extended to the same extent with the maximum extension of the healthy wrist without causing pain. The other stimulation parameters were the same as those of the control group, and the stimulation duration was 10 minutes in both groups. In each task, the oxygenated hemoglobin (HbO_2) in bilateral prefrontal cortex (PFC), primary motor cortex (M1) and primary sensory cortex (S1) of stroke patients were measured by the 35-channel FNIRS, and the differences in overall functional connectivity (FC) strength and mean FC strength based on region of interest (ROI) level between the two groups were analyzed. **Results:** Compared with the control group, the overall connectivity strength of brain regions in the observation group was higher, the FC in the contralateral primary motor cortex (cM1) and ipsilateral prefrontal cortex (iPFC), the cM1 and ipsilateral primary motor cortex, and the intact primary sensory cortex (cS1) and iPFC were significantly higher, and the differences were statistically significant (P<0.05). **Conclusion:** CCNMES can trigger the sensorimotor stimulation of the affected upper limb through the active movement of the healthy upper limb, and induce the functional reorganization of the cerebral cortex in stroke patients with hemiplegia.

KEY WORDS stroke; hemiplegia; contralaterally controlled neuromuscular electrical stimulation; functional near-infrared spectroscopy; cerebral cortex
DOI:10.3724/SP.J.1329.2023.06004