文章编号:1004-7220(2022)02-0348-07

四点跪位和手足位训练中躯干肌肉激活和共收缩模式比较

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摘要:目的 分析四点跪位和手足位训练在躯干肌肉活动和共收缩模式上的异同,探究手足位训练作为核心稳定性训练的可能性,并为实际训练提供建议。**方法** 19 名健康受试者参与研究,随机执行四点跪位(4 个)和手足位(3 个)动作,同时测量两侧腹直肌、腹外斜肌、竖脊肌、多裂肌的表面肌电信号。分析并比较基于表面肌电信号,得到肌电平均振幅值和肌肉共收缩指数。**结果** 四点跪位和手足位训练的组内和组间比较中,单一肌肉激活程度和共收缩指数都表现出统计学差异。四点跪位右手左腿抬起时,所有肌肉激活程度都高于起始位。四点跪位左腿抬起时同侧多裂肌明显高于手足位。手足位右手抬时腹外斜肌和腹直肌激活度较高。对 8 条肌肉两两匹配对共得到 28 种肌肉配对方式,四点跪位起始姿势波动最小,说明脊椎最为稳定,而其他动作指数波动范围较大。**结论** 从肌肉激活程度和共收缩两方面,证明了手足位训练作为核心稳定性训练的可能性。手足位训练和四点跪位训练可分别用于腹部肌肉和背部肌肉锻炼,而对侧上下肢抬起时,腹肌和背肌都能得到很好的锻炼,但需注意避免运动损伤。

关键词: 四点跪位; 表面肌电; 共收缩指数; 核心稳定性训练
中图分类号: R 318.01 **文献标志码:** A
DOI: 10.16156/j.1004-7220.2022.02.025

Comparison of Muscle Activation and Co-Contraction Patterns for Trunk Muscles During Four-Point Hand-Knee and Hand-Foot Kneeling Positions

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Abstract: Objective To analyze the similarities and differences between four-point hand-knee position and hand-foot kneeling positions in trunk muscle activation and co-contraction, explore the possibility of hand-foot kneeling position as core stabilization exercises, so as to provide suggestions for actual training. **Methods** Nineteen healthy volunteers randomly performed exercises of four-point hand-knee position (4 motions) and hand-foot kneeling position (3 motions), while surface electromyography (sEMG) signals were collected from bilateral rectus abdominis, external oblique, erector spine, and multifidus muscles. The average sEMG and muscle co-contraction index (CCI) based on the sEMG signals were analyzed and compared. **Results** Significant differences were found in the sEMG and CCI within and between the two positions. Under four-point hand-knee

收稿日期:2021-03-24; **修回日期:**2021-05-23
基金项目:上海市卫健委科研项目(20184Y0114),上海市体育局全民健身计划项目(21Q002)
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position with the right hand and left leg lifting, the activation of all muscles was higher than that in the starting position. In four-point hand-knee position with the left leg lifting, the activation of ipsilateral multifidus muscle was significantly higher than that in hand-foot kneeling position. The activation degree of external oblique muscle and rectus abdominis was higher in hand-foot kneeling position with right hand lifting. A total of 28 muscle matching methods were obtained by pair-to-pair matching of 8 muscles. The starting posture in four-point hand-knee position fluctuated the least, indicating that the spine was the most stable, while the index of other exercises fluctuated in a larger range. **Conclusions** The possibility of hand-foot kneeling position as core stabilization exercises was proved from two aspects, namely, muscle activation and CCI. The hand-foot kneeling position and four-point hand-knee position can be used for strengthening abdominal muscles and back muscles, respectively. The four-point hand-knee position with contralateral upper and lower limbs lift is a more advanced exercise for trunk muscles, but sports injuries should be avoided.

Key words: four-point kneeling position; surface electromyography (sEMG); co-contraction index; core stabilization exercises

腰痛是常见的肌骨系统问题,脊柱不稳定是主要原因之一[1-4]。核心肌肉在稳定脊柱中扮演重要角色,为远端运动提供近端稳定,使躯干和四肢之间的力量顺利传递[5-6]。核心肌肉包括腹直肌、腹外斜肌、腹内斜肌、竖脊肌、多裂肌等腰腹部肌肉。研究证实,锻炼核心肌肉可以增强脊柱稳定性,从而缓解腰痛[7-8]。

在临床康复中,脊柱低负荷的四点跪位训练及其变式能够不同程度地激活腰腹部肌肉,被推荐作为核心稳定性训练[7,9]。起始位中,腰腹部肌肉激活程度较低[10-12];单侧上肢抬起时,同侧腹横肌肌电活动更高[13];而单侧下肢抬起时,背肌激活度较高,腹部肌肉激活度较低[12,14]。但也有研究报告,同侧腹横肌和腹外斜肌激活较高[15-16]。对侧上下肢同时抬起时,显示腰腹肌均有较高程度的激活[17-18]。核心肌肉协同收缩,稳定躯干,可以通过肌肉共收缩指数(co-contraction index, CCI)反映[9]。但是,目前缺少四点跪位中肌肉共收缩的量化研究。

中国传统功法五禽戏中鹿戏和四点跪位类似。《养性延命录》记载:"鹿戏者,四肢距地,引项反顾,左三右二,左右伸脚,伸缩亦三亦二也"。与四点跪位相比较,鹿戏膝关节不接触地面,仅有手脚触地,故将其称为"手足位"训练。临床研究证明,五禽戏可以锻炼腰骶部肌肉增加脊柱稳定性,减轻腰痛症状,但是并没有单独分析手足位中的腰腹部肌肉活动[19-20]。传统五禽戏中只有下肢抬起,本研究中增加了上肢抬起,丰富其运动形式。本文通过比较四点跪位和手足位训练中触地模式和肢体抬起对肌肉激活和共收缩模式的影响,希望能够丰富四点位核心训练的形式,为临床应用提供针对性建议。

1 材料与方法

1.1 研究对象

19 名健康成年人(12 名男性和 7 名女性),年龄(21.8±0.9) 岁,身高(169.9±9.5) cm,体重(61.9±10.2) kg,体质量指数(body mass index, BMI)(21.3±2.0) kg/m^2。所有受试者均无腰痛或其他肌肉骨骼系统疾病。实验开始前,所有受试者均签署知情同意书。

1.2 实验设计

使用 Noraxon Tele Myo DTS (Noraxon 公司, 美国) 采集表面肌电信息(surface electromyography, sEMG),采样频率 1.5 kHz。用酒精清洁皮肤降低阻抗,再将自粘 Ag/AgCL 表面电极平行于肌纤维方向放置,两电极中心相距 2 cm。8 个电极片分别放置在两侧腹直肌、腹外斜肌、竖脊肌和多裂肌肌腹隆起的位置。然后进行最大自主收缩测试(maximum voluntary contraction, MVC),测试分两次,每次持续 5 s,为避免受试者疲劳,中间至少休息 2 min[21]。测试方法如下:① 腹直肌,受试者呈仰卧起坐位,双腿固定,测试者在双肩施加阻力,限制其抬离床面[22]。② 腹外斜肌,受试者姿势同上,测试者对肩部施加阻力,限制躯干向左或向右旋转[21]。③ 竖脊肌和多裂肌,受试者俯卧位,下肢固定,背伸

对抗施于双肩的阻力[21-23]。受试者在进行热身运动后,由专业人士指导学习测试动作,确保动作标准[见图 1(a)]。正式实验中,受试者在指令下完成动作,顺序随机,每个动作持续 10 s,休息 1 min,重复 1 次,不同动作间休息 2 min,在肌肉充分激活同时避免疲劳[10,15]。

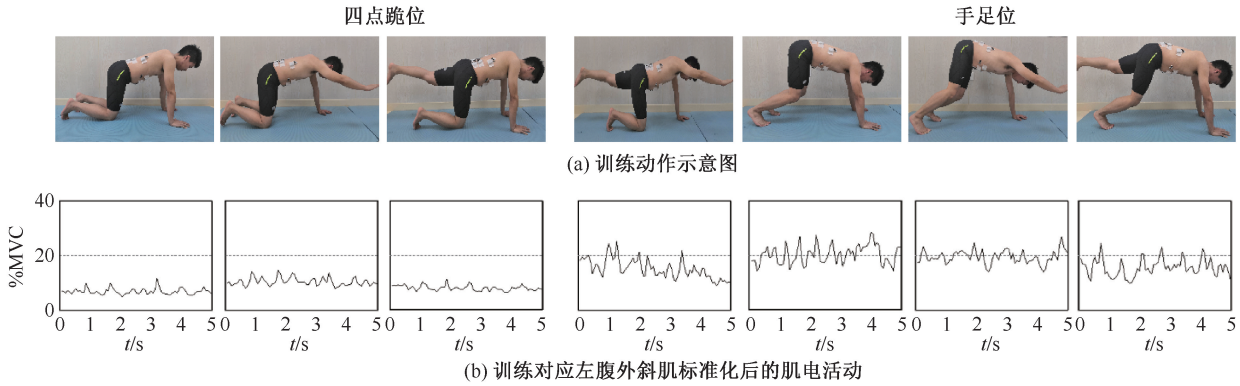

图 1 两种姿势训练示意图及相应的肌电活动

Fig.1 Diagram of exercises and corresponding EMG activity in two positions (a) Diagrams of exercises, (b) Corresponding EMG activity of the left external oblique muscle

1.3 数据处理

原始肌电数据用 Matlab 编写程序处理,截取中间 5 s 数据进行带通滤波(20~500 Hz),全波整流,以 100 ms 时间窗口移动计算均方根(root mean square, RMS),根据每条肌肉的 MVC 平均值作标准化处理,得到标准化后的平均振幅值[见图 1(b)]。

使用 CCI 来量化每对肌肉的共收缩程度,8 条肌肉两两配对,共有 28 种配对方式,分析腹背部肌肉的激活水平之间的关系,深入理解肌肉激活模式[24]。CCI 的计算公式如下[25]:

$$CCI(t) = \frac{2Input_L(t)}{Input_L(t) + Input_H(t)}$$

其中:$Input_L$ 和 $Input_H$ 分别表示 t 时刻配对的两条肌肉中标准化后绝对值较低的肌电信号和绝对值较高的肌电信号,计算每对肌肉共收缩指数的均值。

1.4 统计分析

用 SPSS 22.0 进行统计学分析,计量资料用均值±标准差表示。四点跪位和手足位组内不同动作对肌肉激活和共收缩的影响用重复测量分析比较,Bonferroni 法进行事后分析。采用配对 t 检验比较肢体动作相同时,膝关节触地与否对肌肉活动的影响。$P<0.05$ 表示差异具有统计学意义。

2 结果

2.1 肌肉激活程度

四点跪位和手足位姿势肌电活动的结果如表 1 所示。

表 1 四点跪位和手足位姿势肌电活动及重复测量结果(*$P<0.05$)

Tab.1 sEMG and repeated measure ANOVA results under four-point hand-knee position and hand-foot kneeling position 单位:%MVC

肌肉	四点跪位				P	手足位			P
	起始位	右手抬起	左腿抬起	右手左腿抬起		起始位	右手抬起	左腿抬起	
左腹直肌	0.59±0.05[a]	7.4±1.94[c]	7.69±1.85	9.32±1.68	0.002*	12.76±4.33	15.74±3.76	8.84±1.56	0.037*
右腹直肌	0.54±0.05	5.70±1.41	6.49±1.55	6.90±1.48	0.174	8.68±1.53	11.04±1.67	9.11±1.74	0.644
左腹外斜肌	4.19±0.56[abc]	30.78±5.32[b]	18.06±3.56[c]	24.92±3.49	0.003*	17.23±3.28[a]	39.52±5.62[b]	18.61±3.14	0.081
右腹外斜肌	4.98±0.68[abc]	9.91±1.04	8.75±1.40	11.71±1.38	0.298	19.70±2.59	18.81±2.33	18.94±2.21	0.423
左竖脊肌	2.72±0.42[bc]	8.23±1.90[bc]	24.75±5.52	23.51±4.50	0.012*	4.94±0.96	6.71±1.39	5.94±1.27	0.586
右竖脊肌	2.38±0.41[abc]	7.86±1.05[c]	9.61±1.21[c]	18.55±1.87	0.298	4.75±0.85[a]	11.60±1.97	8.10±1.56	0.268
左多裂肌	4.53±0.79[abc]	13.19±2.40[bc]	33.60±4.01	35.35±5.19	0.012*	7.30±1.16[b]	9.29±1.62[b]	12.69±2.52	<0.001*
右多裂肌	4.19±0.65[bc]	6.19±1.08[bc]	14.73±2.25	22.01±3.99	0.048*	7.28±1.61	10.76±3.25	10.44±1.86	<0.001*

注:a、b、c 分别表示事后检验中,与右手抬起、左腿抬起、右手左腿抬起相比有统计学差异。

测试肌肉在四点跪位不同动作中的激活程度有统计学差异。右手左腿抬起动作中,所有肌肉的肌电活动均明显高于起始位($P<0.05$);背部肌肉激活高于右手抬起($P<0.05$);腹部肌肉中,仅左腹直肌激活明显高于右手抬起,左腹外斜肌激活明显高于左腿抬起。单侧肢体抬起相较于起始位,部分肌肉活动明显增加。

手足位训练中,左腹直肌、左腹外斜肌、左多裂肌和右竖脊肌的激活程度在不同动作中有统计学差异。右手抬起时,左腹外斜肌肌电活动显著增加;左腿抬起时,左多裂肌的激活度明显高于其他两个动作。

比较膝关节触地与否对肌肉激活的影响发现,在起始位姿势,手足位中两侧腹直肌、竖脊肌以及右腹外斜肌的激活明显高于四点跪位。右手抬起时,手足位中多数肌肉激活数值较高,但仅右腹外斜肌明显高于四点跪位($P<0.05$)。左腿抬起时,四点跪位左侧背肌激活明显高于手足位(见表 2)。

表 2　四点跪位和手足位姿势肌电活动配对 *t* 检验结果($^*P<0.05$)

Tab.2　Paired *t* test results of sEMG between the four point hand-knee and hand-foot kneeling positions

肌肉	起始位		右手抬起		左腿抬起	
	t	*P*	*t*	*P*	*t*	*P*
左腹直肌	−2.45	0.034*	−1.816	0.099	−1.228	0.248
右腹直肌	−3.668	0.004*	−1.778	0.106	−0.952	0.363
左腹外斜肌	−1.607	0.139	−1.577	0.146	−0.272	0.791
右腹外斜肌	−4.433	0.001*	−2.340	0.041*	−1.842	0.095
左竖脊肌	−2.980	0.014*	0.443	0.667	3.648	0.004*
右竖脊肌	−2.770	0.020*	−1.748	0.111	1.111	0.292
左多裂肌	−0.836	0.423	2.190	0.053	6.385	<0.001*
右多裂肌	−1.879	0.090	−1.616	0.137	2.012	0.072

2.2　肌肉共收缩

四点跪位起始位中,肌肉配对后的 CCI 处于比较稳定的水平(0.54~0.75),而右手抬起、左腿抬起、右手左腿抬起这 3 个动作 CCI 波动较大(分别为 0.28~0.67、0.28~0.71、0.29~0.69)。手足位中 CCI 的波动范围也较大(起始位:0.38~0.74;右手抬起:0.28~0.75;左腿抬起:0.39~0.80)。

四点跪位中不同动作比较显示,13 种配对方式有统计学差异,多为起始位 CCI 较高。手足位中 7 种配对方式存在显著性差异,多体现于右手抬起时 CCI 较低(见表 3)。

配对 *t* 检验结果显示,在两种训练的起始位,7 种肌肉配对中 CCI 有显著差异,6 种是四点跪位较高。右手抬起和左腿抬起时,各有 11 种和 8 种配对方式存在统计学差异多为手足位 CCI 较高(见表 3)。

3　讨论

标准化后的平均振幅反映肌肉激活情况,动作越困难,肌肉激活越高[26]。可将标准化后的肌肉激活程度分为高度(>20%)、中度(10~20%)和低度(<10%)[16]。本文发现,四点跪位起始位所有肌肉都处在低激活水平,这也与前人的研究结果一致[12];而手足位起始姿势中有 3 条肌肉中度激活(都为腹部肌肉),且腹肌和竖脊肌激活显著高于四点跪位。因此,本文认为在起始姿势中手足位的训练难度更大。

右手抬起时,两种训练的左腹外斜肌都高度激活(>30%),而手足位中右腹外斜肌的激活明显高于四点跪位,且腹直肌等更多肌肉处于中度激活水平。上述结果表明,当单侧上肢抬起时,手足位对腹外斜肌和腹直肌等肌肉要求更高。四点跪位左腿抬起时,左侧背部肌肉高度激活,且显著高于手足位中相应肌肉,可见单侧下肢抬起时,四点跪位更适用于锻炼同侧背部肌肉。

四点跪位右手左腿抬起时,除腹直肌外,其他肌肉都处于中高度激活状态。对侧上下肢抬起时,多数肌肉激活程度明显高于起始位,相当或高于单一肢体抬起,这也与之前的研究一致[12,15]。本文认为,四点跪位训练中,抬起对侧上下肢动作难度最大,可以同时锻炼腹背部肌肉。

肌肉共收缩产生关节刚度,以提高肢体运动时的稳定性和准确性[27]。通过锻炼可以提高 CCI,改善关节不稳[28-29]。起始姿势中,四点跪位 CCI 波动最小,且处于比较高的水平,提示此时脊柱更稳定。单侧肢体抬起时,配对检验结果显示手足位中 CCI 较高,提示手足位稳定性可能较好。但有研究指出,肌肉共收缩和背痛之间存在循环关系,腰痛患者为减轻关节不稳导致的疼痛,肌肉激活和共收缩水平提高,增加躯干刚度,而长此以往又会引发疼

表 3 四点跪位和手足位姿势肌肉共收缩指数重复测量及配对 *t* 检验结果($^*P<0.05$)

Tab.3 Repeated measure ANOVA and paired *t* test results of co-contraction index under four-point hand-knee and hand-foot kneeling positions

肌肉配对	四点跪位训练				*P*	手足位训练			*P*
	起始位	右手抬起	左腿抬起	右手左腿抬起		起始位	右手抬起	左腿抬起	
左腹直肌/左腹外斜肌	0.59±0.05[a]	0.34±0.06[b]	0.51±0.07	0.43±0.07	0.002*	0.54±0.07	0.43±0.07[d]	0.50±0.06	0.037*
左腹直肌/左竖脊肌	0.54±0.05	0.48±0.05	0.42±0.08	0.41±0.07	0.174	0.61±0.06	0.59±0.06	0.63±0.05[d]	0.644
左腹直肌/左多裂肌	0.62±0.05[bc]	0.53±0.06	0.34±0.06	0.39±0.07	0.003*	0.68±0.05	0.68±0.05[d]	0.58±0.06[d]	0.081
右腹直肌/右腹外斜肌	0.60±0.05	0.52±0.06	0.61±0.06	0.57±0.07	0.298	0.50±0.07	0.56±0.07	0.52±0.07	0.423
右腹直肌/左竖脊肌	0.63±0.06[c]	0.53±0.06	0.39±0.08	0.40±0.07	0.012*	0.62±0.06	0.65±0.04[d]	0.59±0.05	0.586
右腹直肌/左多裂肌	0.62±0.07[bc]	0.45±0.06[bc]	0.28±0.07	0.27±0.06	0.298	0.68±0.05	0.68±0.05	0.62±0.05[d]	0.268
左腹外斜肌/左竖脊肌	0.57±0.06	0.41±0.08	0.58±0.07	0.56±0.07	0.012*	0.41±0.06[ad]	0.29±0.05[bd]	0.46±0.07	<0.001*
左腹外斜肌/左多裂肌	0.65±0.06	0.50±0.06	0.54±0.05	0.66±0.06	0.048*	0.51±0.06[abd]	0.37±0.06[bd]	0.61±0.05	<0.001*
右腹外斜肌/右竖脊肌	0.62±0.06	0.67±0.07	0.67±0.05	0.63±0.05	0.766	0.39±0.06[d]	0.56±0.05	0.47±0.06[d]	0.586
右腹外斜肌/右多裂肌	0.72±0.04	0.68±0.04	0.63±0.04	0.64±0.05	0.376	0.47±0.05[d]	0.54±0.05[d]	0.58±0.06	0.268
左竖脊肌/左多裂肌	0.63±0.06	0.63±0.07	0.66±0.06	0.63±0.06	0.957	0.68±0.05	0.71±0.05	0.63±0.04	0.083
右竖脊肌/右多裂肌	0.66±0.06	0.61±0.05	0.71±0.05	0.69±0.05	0.329	0.70±0.06	0.67±0.04	0.75±0.04	0.299
左腹直肌/右腹外斜肌	0.59±0.05	0.51±0.06	0.58±0.06	0.49±0.06	0.107	0.51±0.07	0.55±0.06	0.52±0.07	0.692
左腹直肌/右竖脊肌	0.56±0.05	0.49±0.07	0.50±0.06	0.42±0.06	0.307	0.68±0.06[d]	0.62±0.05[d]	0.58±0.05	0.336
左腹直肌/右多裂肌	0.59±0.05	0.57±0.06	0.51±0.07	0.51±0.06	0.417	0.67±0.06	0.63±0.06	0.65±0.05	0.807
左腹外斜肌/右腹直肌	0.60±0.07[ac]	0.28±0.06	0.42±0.07[c]	0.31±0.05	<0.001*	0.50±0.07[a]	0.37±0.05[bd]	0.50±0.06	0.001*
右腹直肌/左竖脊肌	0.63±0.06	0.53±0.06	0.39±0.08	0.40±0.07	0.009*	0.62±0.05	0.61±0.04	0.62±0.05[d]	0.978
右腹直肌/左多裂肌	0.62±0.07[bc]	0.45±0.06[c]	0.28±0.07	0.27±0.06	<0.001*	0.68±0.05	0.68±0.04[d]	0.62±0.07[d]	0.336
左腹外斜肌/右竖脊肌	0.54±0.05	0.44±0.06[bc]	0.60±0.06	0.65±0.05	0.001*	0.45±0.07	0.44±0.06	0.54±0.06	0.153
左腹外斜肌/右多裂肌	0.57±0.06[ac]	0.33±0.04[bc]	0.66±0.05	0.64±0.05	<0.001*	0.46±0.04[a]	0.31±0.05[b]	0.57±0.05	<0.001*
右腹外斜肌/左竖脊肌	0.66±0.05	0.65±0.05	0.52±0.07	0.57±0.06	0.168	0.38±0.06[ad]	0.51±0.07	0.39±0.05	0.029*
右腹外斜肌/左多裂肌	0.69±0.05[bc]	0.63±0.06[b]	0.37±0.05[c]	0.46±0.05	<0.001*	0.50±0.05[d]	0.57±0.05	0.58±0.05[d]	0.209
左竖脊肌/右多裂肌	0.71±0.05	0.67±0.05	0.61±0.06	0.64±0.05	0.153	0.69±0.06	0.58±0.05	0.65±0.05	0.123
左多裂肌/右竖脊肌	0.57±0.07[a]	0.59±0.06	0.45±0.06	0.62±0.06	0.032*	0.65±0.06	0.65±0.05	0.70±0.05[d]	0.618
左腹直肌/右腹直肌	0.75±0.04	0.67±0.05	0.72±0.05	0.67±0.06	0.013*	0.75±0.05	0.73±0.04[d]	0.72±0.04	0.595
左腹外斜肌/右腹外斜肌	0.67±0.05	0.52±0.05	0.62±0.05	0.56±0.05	0.028	0.73±0.05[a]	0.52±0.05[b]	0.69±0.05	0.001*
左竖脊肌/右竖脊肌	0.68±0.06	0.58±0.06	0.57±0.06	0.66±0.05	0.052	0.69±0.06	0.58±0.05	0.65±0.05	0.171
左多裂肌/右多裂肌	0.70±0.05	0.61±0.07	0.56±0.06	0.6±0.06	0.052	0.74±0.06	0.75±0.05[d]	0.80±0.04[d]	0.207

注:a、b、c 分别表示事后检验中,与右手抬起、左腿抬起、右手左腿抬起相比有统计学差异;d 表示肢体动作相同时,四点跪位和手足位配对 *t* 检验结果有统计学差异。

痛[24,30-31]。因此,在训练中需要避免共收缩水平过低导致锻炼效果不佳,或过高而引起疼痛。四点跪位对侧上下肢同时抬起时,CCI 数值上与单侧肢体抬起时相当,但该动作下多数肌肉在中、高度激活水平进行共收缩,练习时需要注意休息和动作规范,以免造成损伤。

结合以上讨论可知,手足位训练能够区别于四点跪位训练锻炼腰腹部肌肉,提供不同的肌肉激活模式和脊柱稳定性,提示手足位训练作为可作为四点跪位的补充,丰富核心稳定性训练。

本研究的局限性如下:只对部分腰腹部肌肉进行测量,缺少深层核心肌肉的活动信息,如腹内斜肌和腹横肌,未能分析两种训练对深层腹肌的锻炼效果。希望未来的研究能够更全面地监测腰腹肌肌肉活动,并通过临床试验验证其锻炼效果。

4 结论

本文从肌肉激活程度和共收缩两方面,证明手足位训练作为核心稳定性训练的可能性,并提供细致的指导意见。从肌肉锻炼角度,手足位更适用腹部肌肉锻炼,尤其是上肢抬起时;四点跪位下肢抬起可用于背部肌肉锻炼,对侧上下肢抬起适用更高阶的锻炼。在脊柱稳定性上,对侧上下肢抬起时由于要求肌肉高水平共收缩,需注意避免运动损伤。因此,建议医生、治疗师和体能教练可参考本研究结果,帮助训练者制定个性化训练计划,提高训练效率。

参考文献:

[1] GBD 2019 Diseases and Injuries Collaborators. Global burden of 369 diseases and injuries in 204 countries and territories, 1990-2019: A systematic analysis for the Global Burden of Disease Study 2019 [J]. Lancet, 2020, 396 (10258): 1204-1222.

[2] 张帅, 王宽, 姜成华, 等. 穿戴模拟重力服对微重力环境下人腰椎间盘退变影响[J]. 医用生物力学, 2020, 35(1): 64-69.
ZHANG S, WANG K, JIANG CH, *et al*. Effects of gravity loading countermeasure garment on degeneration of lumbar intervertebral disc in microgravity environment[J]. J Med Biomech, 2020, 35(1): 64-69.

[3] O'SULLIVAN PB. Lumbar segmental 'instability': Clinical presentation and specific stabilizing exercise management [J]. Man Ther, 2000, 5(1):2-12.

[4] 欧阳钧, 钱蕾, 孙培栋. 脊柱生物力学研究的回顾与展望[J]. 医用生物力学, 2021, 36(2): 169-176.
OUYAN J, QIAN L, SUN PD. Retrospect and prospect on researches of spine biomechanics [J]. J Med Biomech, 2021, 36 (2): 169-176.

[5] ESSENDROP M, ANDERSEN TB, SCHIBYE B. Increase in spinal stability obtained at levels of intra-abdominal pressure and back muscle activity realistic to work situations [J]. Appl Ergon, 2002, 33 (5): 471-476.

[6] WIRTH K, HARTMANN H, MICKEL C, *et al*. Core stability in athletes: A critical analysis of current guidelines [J]. Sports Med, 2017, 47(3): 401-414.

[7] OLIVA-LOZANO JM, MUYOR JM. Core muscle activity during physical fitness exercises: A systematic review [J]. Int J Environ Res Public Health, 2020, 17(12): 4306.

[8] HIBBS AE, THOMPSON KG, FRENCH D, *et al*. Optimizing performance by improving core stability and core strength [J]. Sports Med, 2008, 38(12): 995-1008.

[9] MCGILL S. Core training: Evidence translating to better performance and injury prevention [J]. Strength Cond J, 2010, 32(3): 33-46.

[10] CHANTHAPETCH P, KANLAYANAPHOTPORN R, GAOGASIGAM C, *et al*. Abdominal muscle activity during abdominal hollowing in four starting positions [J]. Man Ther, 2009, 14(6): 642-646.

[11] BEITH ID, SYNNOTT RE, NEWMAN SA. Abdominal muscle activity during the abdominal hollowing manoeuvre in the four point kneeling and prone positions [J]. Man Ther, 2001, 6(2): 82-87.

[12] SAKULSRIPRASERT P, EAK-UDCHARIYA P, JALAYO-NDEJA W. Muscle activity of abdominal and back muscles during six starting positions in untrained individuals [J]. J Med Assoc Thai, 2015, 98(Suppl 5): S125-130.

[13] PIROUZI S, EMAMI F, TAGHIZADEH S, *et al*. Is abdominal muscle activity different from lumbar muscle activity during four-point kneeling? [J]. Iran J Med Sci, 2013, 38(4): 327-333.

[14] MASAKI M, TATEUCHI H, TSUKAGOSHI R, *et al*. Electromyographic analysis of training to selectively strengthen the lumbar multifidus muscle: effects of different lifting directions and weight loading of the extremities during quadruped upper and lower extremity lifts [J]. J Manipulative Physiol Ther, 2015, 38(2): 138-144.

[15] BJERKEFORS A, EKBLOM MM, JOSEFSSON K, *et al*. Deep and superficial abdominal muscle activation during trunk stabilization exercises with and without instruction to hollow [J]. Man Ther, 2010, 15(5): 502-507.

[16] STEVENS VK, COOREVITS PL, BOUCHE KG, *et al*. The influence of specific training on trunk muscle recruitment patterns in healthy subjects during stabilization exercises [J]. Man Ther, 2007, 12(3): 271-279.

[17] BISCARINI A, CONTEMORI S, GROLLA G. Activation of scapular and lumbopelvic muscles during core exercises executed on a whole-body wobble board [J]. J Sport Rehabil, 2019, 28(6): 623-634.

[18] IMAI A, KANEOKA K, OKUBO Y, *et al*. Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface [J]. J Orthop Sports Phys Ther, 2010, 40 (6): 369-375.

[19] 白玉花, 董利薇, 王军如, 等. 五禽戏对改善腰骶部多裂肌功能的影响[J]. 中国康复医学杂志, 2012, 27(4): 368-368.

[20] GUO Y, XU M, WEI Z, *et al*. Beneficial effects of qigong wuqinxi in the improvement of health condition, prevention, and treatment of chronic diseases: Evidence from a systematic review [J]. Evid Based Complement Alternat

Med, 2018: 3235950.

[21] WONG AY, PARENT EC, PRASAD N, *et al*. Does experimental low back pain change posteroanterior lumbar spinal stiffness and trunk muscle activity? A randomized crossover study [J]. Clin Biomech, 2016, 34: 45-52.

[22] EKSTROM RA, DONATELLI RA, CARP KC. Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises [J]. J Orthop Sports Phys Ther, 2007, 37(12): 754-762.

[23] DANNEELS LA, STRAETEN GG, CAMBIER DC, *et al*. A functional subdivision of hip, abdominal, and back muscles during asymmetric lifting [J]. Spine, 2001, 26(6): E114-121.

[24] SCHINKEL-IVY A, NAIRN BC, DRAKE JD. Investigation of trunk muscle co-contraction and its association with low back pain development during prolonged sitting [J]. J Electromyogr Kinesiol, 2013, 23 (4): 778-786.

[25] FALCONER K, WINTER DA. Quantitative assessment of co-contraction at the ankle joint in walking [J]. Electromyogr Clin Neurophysiol, 1985, 25(2-3): 135-149.

[26] OLIVEIRA ADE S, GONÇALVES M. Lumbar muscles recruitment during resistance exercise for upper limbs [J]. J Electromyogr Kinesiol, 2009, 19(5): 737-745.

[27] LI G, SHOURIJEH MS, AO D, *et al*. How well do commonly used co-contraction indices approximate lower limb joint stiffness trends during gait for individuals post-stroke? [J]. Front Bioeng Biotechnol, 2020, DOI: 10.3389/fbioe.2020.588908.

[28] LEWEK MD, RUDOLPH KS, SNYDER-MACKLER L. Control of frontal plane knee laxity during gait in patients with medial compartment knee osteoarthritis [J]. Osteoarthr Cartil, 2004, 12(9): 745-751.

[29] SOUISSI H, ZORY R, BREDIN J, *et al*. Co-contraction around the knee and the ankle joints during post-stroke gait [J]. Eur J Phys Rehabil Med, 2018, 54(3): 380-387.

[30] JAAP HVD, LUC PJS, CHOLEWICKI J. Trunk muscle activation in low-back pain patients, an analysis of the literature [J]. J Electromyogr Kinesiol, 2003, 13(4): 333-351.

[31] COLLOCA, CJ, HINRICHS, RN. The biomechanical and clinical significance of the lumbar erector spinae flexion-relaxation phenomenon: A review of literature [J]. J Manipulative Physiol Ther, 2005, 28(8): 623-631.