



血流限制训练对老年肌少症患者肌力及躯体功能的影响*

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【摘要】目的 探讨血流限制训练对住院老年肌少症患者肌肉力量、躯体功能、功能性移动能力及日常生活活动能力的影响,并比较其与传统抗阻训练的差异,为临床制定康复策略提供科学依据。**方法** 本研究采用随机对照试验设计,共纳入40例经临床诊断为肌少症的住院老年患者,按1:1比例通过计算机生成随机分配序列分为试验组和对照组,各20例。试验组进行血流限制训练,对照组进行抗阻训练,干预持续12周,每周3次。分别于干预前、第4周及第12周对受试者进行评估。主要结局指标为肌肉力量,用优势手握力评估。次要结局指标包括躯体功能、功能性移动能力和日常生活活动能力,分别用简易体能状况量表(short physical performance battery, SPPB)、6 m步速和计时起立—行走测试(timed up and go test, TUG)以及改良的Barthel指数(modified barthel index, MBI)进行测量。**结果** 研究期间无失访,无不良事件发生。干预4周后,两组主要结局指标握力均较基线提升(均 $P<0.001$),试验组握力 $[(24.35\pm 5.43)\text{ kg}]$ 高于对照组 $[(20.96\pm 5.25)\text{ kg}]$,但两组间差异无统计学意义($P=0.051$);在次要结局指标方面,试验组在SPPB评分和MBI评分方面均明显优于对照组(均 $P<0.05$),TUG测试和6 m步速差异尤为明显($P<0.01$)。干预12周后,主要结局指标握力在组间差异上具有统计学意义[试验组 $(25.25\pm 5.34)\text{ kg}$,对照组 $(21.66\pm 5.26)\text{ kg}$, $P=0.039$]。在次要结局指标方面,试验组在SPPB评分、6 m步速、TUG测试时间和MBI评分方面均明显优于对照组(均 $P<0.01$)。**结论** 血流限制训练能够明显改善住院老年肌少症患者的肌力、提高老年人躯体功能、功能性移动能力及日常生活活动能力,其效果优于抗阻训练。

【关键词】 血流限制训练 肌少症 肌肉力量 老年患者

Effects of Blood Flow Restriction Training on Muscle Strength and Physical Function in Older Adults With Sarcopenia

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【Abstract】 Objective To investigate the effects of blood flow restriction (BFR) training on muscle strength, physical function, functional mobility, and activities of daily living (ADL) in hospitalized older adults with sarcopenia, and to compare its efficacy with that of traditional resistance training (RT), thereby providing a research basis for the development of clinical rehabilitation strategies. **Methods** In this randomized controlled trial, 40 hospitalized older adults clinically diagnosed with sarcopenia were enrolled. By using a computer-generated randomization sequence, the participants were randomly assigned at a 1:1 ratio to an experimental group ($n=20$) receiving BFR training or a control group ($n=20$) receiving RT. Both groups underwent a 12-week supervised program, with training sessions conducted 3 times per week. Outcome measures were assessed at baseline, 4 weeks, and 12 weeks. The primary outcome measure was muscle strength, assessed by dominant-hand grip strength. Secondary outcomes included physical function assessed with the Short Physical Performance Battery (SPPB), functional mobility assessed by the 6-meter (6-m) gait speed and the Timed Up and Go (TUG) test, and ADL assessed with the Modified Barthel Index (MBI). **Results** No participants were lost to follow-up, and no adverse events were reported. After 4 weeks of intervention, grip strength improved significantly in both groups compared with the baseline data (all $P<0.001$), with the BFR group demonstrating higher grip strength than the RT group $[(24.35\pm 5.43)\text{ kg}$ vs $(20.96\pm 5.25)\text{ kg}]$, although the between-group difference was not statistically significant ($P=0.051$). Regarding secondary outcomes, the BFR group showed significant improvements in SPPB and MBI scores compared with the RT group (all $P<0.05$), with the most pronounced differences in TUG performance and 6-m gait speed ($P<0.01$). After 12 weeks of intervention, grip strength was significantly higher in the BFR group than that

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in the RT group ($[25.25 \pm 5.34]$ kg vs. $[21.66 \pm 5.19]$ kg; $P = 0.039$). Moreover, the BFR group demonstrated significantly better outcomes in SPPB score, 6-m gait speed, TUG time, and MBI score than the RT group did (all $P < 0.01$).

Conclusion BFR training significantly improves muscle strength, physical function, functional mobility, and ADL in hospitalized older adults with sarcopenia, showing superior efficacy compared with conventional RT.

[Key words] Blood flow restriction training Sarcopenia Muscle strength Elderly patient

肌少症是一种与年龄增长相关的渐进性全身骨骼肌病变,其核心症状包括肌肉量减少、肌力下降及/或躯体功能减退^[1]。流行病学研究显示,全球60岁以上老龄人口的肌少症发病率达10%~27%^[2],我国老年人群总患病率为18.4%^[3]。在住院老年人群中,由于活动受限及共病等因素,肌少症发生率更高,常导致功能衰退加剧、住院时间延长及医疗负担加重^[4-6]。传统抗阻训练虽为主要推荐的运动干预方式,但其高负荷特性对常伴多种疾病、虚弱或耐受性差的住院老年人而言,实施依从性与安全性面临挑战^[7-8]。近年来,血流限制训练(blood flow restriction training, BFRT)作为一种抗阻训练替代方案广受关注^[9]。它通过在运动肢体近端加压,部分限制血流,使患者在低负荷下运动,即可模拟高强度训练引发的肌肉适应^[10-11]。已有研究证实BFRT对健康及社区老年肌少症人群的肌力、肌肉量等功能有改善作用且具备安全性^[11-12]。然而,现有研究针对住院老年肌少症患者的研究较少且功能评估多限于肌力与肌肉质量,缺乏对躯体功能与日常活动能力的多维综合评估。因此,本研究旨在通过随机对照试验,探讨BFRT对住院老年肌少症患者躯体功能的影响,综合评估其肌力、步行速度及功能独立性等方面的干预效果。

1 资料与方法

1.1 研究对象

本研究于2024年8月至2025年8月在四川大学华西医院招募老年肌少症住院患者,受试者经过严格筛查并签署知情同意后入组。纳入标准:(1)符合亚洲肌少症工作组2019年制定的肌少症诊断标准^[13-14];(2)年龄>65岁,自身基础疾病稳定、生命体征平稳;(3)可以日常沟通并能理解与合作。排除标准:(1)存在重度功能障碍(MBI ≤ 40 分或依赖轮椅/卧床);(2)严重认知功能障碍或其他精神疾病;(3)血流限制训练禁忌证:深静脉血栓形成史或潜在危险、凝血功能障碍、静脉曲张等。以主要结局指标握力为依据进行样本量估算:采用G*Power 3.1软件,设定双侧 $\alpha = 0.05$ 、检验效能80%,预估所需最小样本量为28例;考虑到约20%的脱落及不依从风险,最终纳入40例临床诊断为肌少症的老年住院患者。

1.2 试验方法

本研究为一项随机对照试验,方案已经四川大学华

西医院生物医学伦理委员会批准,批准号2024年审(2579)号,并在ClinicalTrials.gov注册(注册号:NCT06986395)。40例纳入者按1:1比例随机分为试验组和对照组。随机分配序列由计算机生成,对结局评估者、数据采集与统计分析人员实施设盲。两组干预均为每周3次,每次30 min,持续12周,并分别于干预前、第4周和第12周进行评估:主要结局指标为握力,次要结局指标包括简易体能状况量表(short physical performance battery, SPPB)评分、6米步速、计时起立—行走测试(timed up and go test, TUG)时间及改良 Barthel 指数(modified barthel index, MBI)评分。所有干预及评估措施均由经培训人员规范实施。干预主要在患者住院期间完成,对于在研究周期内部分病情稳定提前出院的患者,提供详细的家庭训练指导与简易设备,并通过每周电话或视频随访确保干预依从性与规范性,所有患者均按计划返院完成各时间点评估。研究流程见图1。

1.3 干预方法

所有患者随机分组后,进行运动安全宣教及常规护理,并间接测量患者上下肢的一次最大重复值(one repetition maximum, 1RM)^[15],两组训练过程均由专业、经验丰富的康复治疗师进行一对一指导,试验组接受血流限制训练,对照组进行常规抗阻训练。

1.3.1 血流限制训练干预

该方案以“低负荷血流限制训练”为核心,加压设置如下:上肢训练时加压带置于上臂上1/3处,下肢训练时置于大腿近心端距腹股沟5~10 cm处^[16];初始压力设定参考肢体围度及既往文献(上肢80~100 mmHg、下肢150~200 mmHg, 1 mmHg = 0.133 kPa),并根据患者主观耐受度(RPE评分12~14分)及皮肤颜色、末梢循环情况进行个体化调整^[17];并于每组动作前充压、组间维持压力,训练结束后立即释放,根据个体耐受度调整以避免不适。训练参数设定为负荷强度20%~30% 1RM,每组10~15次重复,共完成4组,组间休息60 s,每周3次,每次30 min,持续12周^[18]。单次训练内容包括肱二头肌屈伸、肩部复合动作(前平举、侧平举)以及股四头肌屈伸膝训练,各项均以坐位姿势双侧执行,每组10~15次。

1.3.2 抗阻训练

该方案以中高强度抗阻训练为核心,训练参数设定

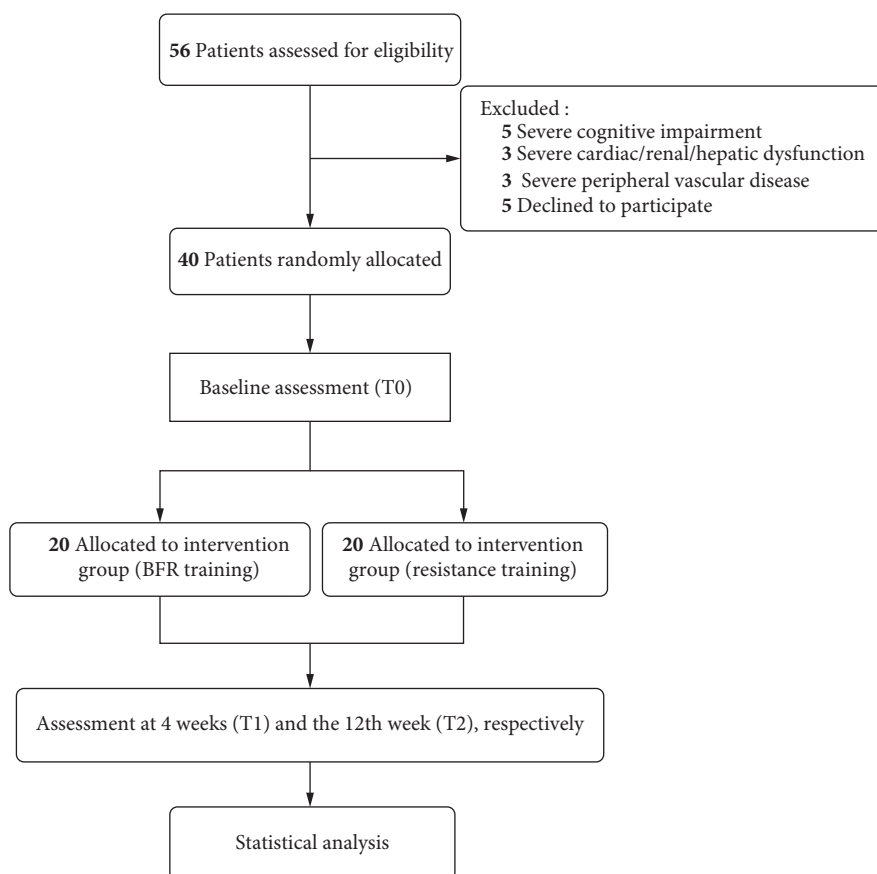


图1 研究流程图

Fig 1 Study flowchart

为负荷强度65%~75% 1RM, 每组10~15次重复, 共完成4组, 组间休息60 s, 每周3次, 每次30 min, 持续12周。单次训练动作内容与试验组相同, 本研究比较的是两种不同训练处方(低负荷BFR vs 中高强度传统抗阻训练)的整体效果, 而非单纯的加压因素。

1.4 观察指标

招募患者后进行基线特征收集, 包括性别、年龄、共病种类等, 干预前、干预4周后(T1时点)和12周后(T2时点)均由受过训练的独立评估员对结局指标进行评估, 评估人员不参与治疗且在采集资料时对受试者的分组情况不知情, 从而保证了资料的客观性。

1.4.1 主要结局指标

采用优势手握力来评估患者的肌肉力量, 在本研究中采用液压握力计(中国电子握力计, 型号 EH-101)进行测量。

1.4.2 次要结局指标

包括SPPB评分、6 m步速、TUG时间及MBI评分, 以评估躯体功能状况、功能性移动能力和日常生活活动能力。

1.5 统计学方法

统计分析均基于SPSS 26.0。连续变量先进行正态性

分布检验, 正态数据以 $\bar{x} \pm s$ 呈现, 不同时间点(基线-4周-12周)的组内比较以重复测量方差分析为主要分析方法, 同时分析组别主效应、时间主效应及组别 $\times$ 时间交互效应。不符合正态分布的数据以中位数表示, 组内比较使用Friedman检验, 组间比较使用Mann-Whitney U 检验。分类变量表示为频数(%), 组间比较选用卡方检验或Fisher精确检验。为验证组间效应、时间效应及其交互效应的稳健性, 进一步采用广义估计方程分析, 必要时对多重比较进行Bonferroni校正; 所有统计检验均为双侧检验, $P < 0.05$ 为差异有统计学意义。

2 结果

2.1 基线资料

研究期间失访0例, 无不良事件发生。两组年龄、性别、BMI、SMI、营养状况、受教育年限等差异均无统计学意义($P > 0.05$)。见表1。

2.2 主要结局指标比较

如表2所示, 与基线相比, 干预4周后, 试验组握力与对照组相比差异无统计学意义($P = 0.051$)。干预12周后, 试验组和对照组握力差异有统计学意义(Bonferroni校正,

表 1 患者基线资料比较

Table 1 Baseline characteristics of the participants

Characteristic	BFRT group (<i>n</i> = 20)	Control group (<i>n</i> = 20)	<i>t</i> / χ^2	<i>P</i>
Age/year	81.65 ± 10.53	79.67 ± 9.94	0.595	0.555
Sex			0.000	1.000
Female	7 (35.0)	7 (35.0)		
Male	13 (65.0)	13 (65.0)		
BMI/(kg/m ²)	22.43 ± 1.90	23.34 ± 2.80	-1.214	0.232
ASMI/(kg/m ²)	5.97 ± 0.66	5.94 ± 0.67	0.147	0.884
Nutritional status			0.472	0.790
Malnutrition	8 (40.0)	10 (50.0)		
At risk	9 (45.0)	7 (35.0)		
Formal education			2.261	0.527
≤ 6 years	3 (15.0)	2 (10.0)		
7-12 years	9 (45.0)	13 (65.0)		
≥ 13 years	8 (40.0)	5 (25.0)		
Hypertension	10 (50.0)	6 (30.0)	1.667	0.197
Diabetes	7 (35.0)	8 (40.0)	0.107	0.744
Stroke history	4 (20.0)	1 (5.0)	2.057	0.151
COPD	3 (15.0)	5 (25.0)	0.625	0.429
CHD	7 (35.0)	5 (25.0)	0.473	0.490

BMI: body mass index; ASMI: appendicular skeletal muscle index; COPD: chronic obstructive pulmonary disease; CHD: coronary heart disease. Data are $\bar{x} \pm s$ or case (%).

$t = 2.138, P = 0.039$)。重复测量方差分析显示, 时间($P < 0.001$)、组别 $\times$ 时间交互效应显著($P_{\text{adj}} < 0.001$)。即两组握力均随干预时间延长而改善, 说明时间因素对主要

结局变化具有重要影响; 但显著的组别 $\times$ 时间交互效应提示, 两组握力改善轨迹并不相同, BFRT组改善幅度更大。

表 2 两组主要结局指标比较

Table 2 Comparison of the primary outcome measure between the two groups

Group	T0 (Baseline)	T1 (4 weeks)	T2 (12 weeks)
BFRT (<i>n</i> = 20)	18.32 ± 5.42	24.35 ± 5.43	25.25 ± 5.34
Control (<i>n</i> = 20)	18.23 ± 4.92	20.96 ± 5.25	21.66 ± 5.26
<i>t</i> / <i>P</i>	0.058/0.954	2.012/0.051	2.138/0.039

$F_{\text{time}} = 622.601, P < 0.001; F_{\text{group}} = 2.026, P = 0.163; F_{\text{interaction}} = 76.926, P_{\text{adj}} < 0.001; \eta^2 p = 0.810$ (Large).

2.3 次要结局指标比较

干预后, 试验组SPPB评分、6 m步速、TUG时间及MBI评分在各时间点均较基线显著改善。干预4周时, 试验组各指标均显著优于对照组, 组间差异均具有统计学意义(均 $P < 0.05$)。至干预12周, 试验组上述指标进一步改善, 与对照组间的差异持续存在且更为显著(均 $P < 0.01$)。见表3。

2.4 安全性评价

两组患者在12周干预期间均未发生严重不良事件。试验组有2例(10%)出现轻度肢体麻木感, 调整加压强度后症状缓解; 1例(5%)出现训练后轻度头晕, 休息后自行缓解。对照组有1例(5%)报告训练后肌肉酸痛, 48 h内自行恢复。两组训练期间心率、血压监测均在安全范围内。

3 讨论

本试验通过一项为期12周的随机对照试验, 首次在住院老年肌少症患者中系统评估了BFRT对肌肉力量、躯体功能、移动能力及日常生活活动能力的综合影响。结

表 3 两组次要结局指标比较

Table 3 Comparison of secondary outcome measures between groups

Group	<i>n</i>	Time	SPPB score	6-meter walking speed/(m/s)	TUG test/s	MBI score
BFRT	20	T0 (baseline)	7.60 ± 1.79	0.60 ± 0.15	11.20 ± 0.89	76.25 ± 12.86
		T1 (4 weeks)	9.55 ± 1.70 ^{***}	0.90 ± 0.15 ^{***}	9.45 ± 0.93 ^{***}	83.75 ± 10.50 ^{***}
		T2 (12 weeks)	11.05 ± 0.94 ^{***}	1.19 ± 0.16 ^{***}	8.25 ± 0.95 ^{***}	89.75 ± 8.81 ^{***}
Control	20	T0 (baseline)	7.10 ± 2.02	0.54 ± 0.13	11.13 ± 0.85	74.50 ± 10.63
		T1 (4 weeks)	8.40 ± 1.73 ^{**,#}	0.74 ± 0.15 ^{***,##}	11.06 ± 0.71 ^{##}	77.25 ± 9.24 ^{**,#}
		T2 (12 weeks)	9.70 ± 1.34 ^{***,##}	0.94 ± 0.14 ^{***,###}	10.46 ± 0.77 ^{**,###}	82.00 ± 8.65 ^{***,##}
<i>F</i> _{time} / <i>P</i>			248.536/< 0.001	2507.236/< 0.001	116.972/< 0.001	101.276/< 0.001
<i>F</i> _{group} / <i>P</i>			4.169/0.048	11.680/0.002	28.885/< 0.001	2.929/0.095
<i>F</i> _{interaction} / <i>P</i> _{adj}			5.354/0.021	96.906/< 0.001	49.744/< 0.001	9.203/< 0.001
<i>η</i> ² <i>p</i>			0.129	0.728	0.730	0.340

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$, vs. T0 in the same group; # $P < 0.05$, ## $P < 0.01$, ### $P < 0.001$, vs. BFRT group at the same time point.

果表明,相较于传统中高强度抗阻训练,BFRT在提升该脆弱人群的肌力与躯体功能等多维功能方面展现出显著优势,且这种改善效应随时间持续增强。

本研究的首要意义在于,将BFRT的应用场景拓展至住院老年肌少症患者这一高脆弱、高风险的群体,并证实了其安全性与有效性。既往研究多集中于健康或慢性病社区人群,对于因急性疾病或手术住院、常伴有多种共病的老年肌少症患者能否耐受并从中获益证据有限^[19-21]。本研究结果显示,BFRT组患者不仅顺利完成12周干预,无严重不良事件发生,且在肌力、躯体功能、移动能力及日常生活活动能力上均取得了显著优于传统训练组的改善。这强有力地证明,BFRT是一种特别适合无法承受中高负荷训练的虚弱住院患者的有效康复策略。

BFRT的优越效果可能源于其独特的生理学机制。短期内(4周),低负荷结合加压导致的局部缺血/再灌注和代谢产物堆积,可有效激活mTOR等合成代谢通路并诱发强烈的代谢应激,促进蛋白质合成^[22-23]。长期来看(12周),这种持续刺激可能通过增强Ⅱ型肌纤维的募集与肥大^[24-26],以及改善神经肌肉控制,从而实现肌力与功能指标的同步提升。本研究中依赖爆发力的步速和依赖力量、平衡与协调的TUG的显著改善,正是神经肌肉适应性增强的有力体现。

需要明确的是,本研究比较的是“低负荷BFRT”与“中高强度传统抗阻训练”两种完整康复处方的整体效果。BFRT的优势在于,它通过加压这一“生理放大器”,使得20%~30% 1RM的极低机械负荷也能产生与传统70%~80% 1RM训练相似甚至更优的肌力与功能增益。这对于疼痛受限、疲劳感强或心血管风险高的住院老年患者而言,极大地提高了训练的可行性与依从性。因此,本研究的结论并非否定传统抗阻训练,而是为临床提供了一种在传统方案不可行或不耐受时的强效替代方案。

本研究另一重要发现是,BFRT的益处形成了一个从基础生理指标到高级功能活动的改善链条。肌力的提升是基石,直接支撑了下肢力量与躯体功能的增强。而步速加快和TUG时间缩短,则标志着功能性移动能力的本质改善,这两项是预测老年人跌倒、失能和死亡风险的强力指标^[27-29]。最终,所有这些身体能力的进步,汇聚体现为MBI评分的显著提高,即日常生活活动独立性的恢复。这证实了BFRT作为一种康复干预,其价值最终落脚于提升患者的整体功能水平和生活质量。

本研究存在若干局限性。首先,尽管样本量估算基于主要结局指标握力,设定 $\alpha=0.05$ 、检验效能80%,但实际纳入40例后统计把握度仅为临界水平;干预4周时握力

组间差异 $P=0.051$,提示存在潜在的Ⅱ类错误风险,样本量相对有限可能影响了中期评估时点结果判定的稳定性,未来研究需扩大样本以验证结果的稳健性。其次,血流限制压力的设定基于肢体围度及文献经验值(上肢80~100 mmHg、下肢150~200 mmHg),未来研究应采用多普勒超声测定个体化动脉闭塞压作为加压标准,以提高加压精准度与可重复性。第三,干预方案无法对受试者和治疗师实施盲法,可能存在性能或测量偏倚,尽管本研究已采取标准化评估指令、由独立于治疗的评估员使用客观设备进行结局测量等措施以控制偏倚,但非盲设计仍可能对主观性指标产生一定影响。最重要的,如前述,本研究比较的是两种不同负荷处方,而非单纯“加压”与“不加压”的对照。未来研究应开展多中心、大样本试验,并利用多普勒超声等技术实现精准化、个体化的加压,同时探索BFRT对肌肉质量、身体成分等更客观指标的长期影响,并进一步优化其在不同亚组患者中的应用方案。

综上所述,本研究表明,对于住院老年肌少症患者,为期12周的低负荷血流限制训练是一项安全、可行的康复干预。与中高强度传统抗阻训练相比,BFRT在改善肌力、躯体功能、功能性移动能力及日常生活活动能力方面展现出显著优势,且效果随时间持续累积。这为临床针对虚弱、耐受性差的老年患者制定高效、安全的个体化康复方案提供了重要的循证依据。

* * *

作者贡献声明 梁玉祥负责论文构思、正式分析、研究方法、软件、可视化、初稿写作和审读与编辑写作, 午玉琦和淳雪丽负责调查研究和研究项目管理, 王锐莉负责论文构思和数据审编, 蒋佼佼负责经费获取、提供资源、监督指导和审读与编辑写作。所有作者已经同意将文章提交给本刊, 且对将要发表的版本进行最终定稿, 并同意对工作的所有方面负责。

Author Contribution Liang Yuxiang is responsible for conceptualization, formal analysis, methodology, software, visualization, writing--original draft, and writing--review and editing. Wu Yuqi and Chun Xueli are responsible for investigation and project administration, Wang Ruili is responsible for conceptualization and data curation. Jiang Jiaojiao is responsible for funding acquisition, resources, supervision, and writing--review and editing. All authors consented to the submission of the article to the Journal. All authors approved the final version to be published and agreed to be accountable for all aspects of the work.

利益冲突 所有作者均声明不存在利益冲突

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