低负荷血流限制训练在肌少症中的研究进展

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摘 要:目的 旨在探讨低负荷血流限制训练(LL-BFR)在肌少症干预中的研究进展,以期为该疾病的预防和治疗提供理论指导和实践参考。**方法** 通过文献资料法阐述 LL-BFR 训练的作用机制以及在肌少症中的应用效果,结合现有研究讨论其目前所面临的问题,并对具体实施策略提出建议。**结果** LL-BFR 训练通过激素分泌、蛋白质合成等机制可达到与高强度训练相似的效果,能显著提高老年人的肌肉力量和质量,并在一定程度上改善血管功能。但该方法仍存在安全问题,如血管疾病和肌肉损伤等不良反应,在方案设计中需注意压力和训练参数的优化设置。**结论** 作为一种耐受性良好的新型手段,LL-BFR 训练在防治肌少症方面具有很大的潜力,有望成为传统运动的替代方案。但目前其临床应用面临一定的局限性和潜在风险,因此需要在科学指导下进行个性化方案的制定和实施。

关键词: 肌少症;低负荷血流限制训练;抗阻训练;老年人
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Research Progress of Low-load Blood Flow Restriction Training in Sarcopenia

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Abstract: Objective To explore the research progress of low-load blood flow restriction (LL-BFR) training in the intervention of sarcopenia, with the aim of providing theoretical guidance and practical reference for the prevention and treatment of this disease. **Methods** Through literature review, this study elaborated on the mechanisms of action of LL-BFR training and its application effects in sarcopenia. Combined with existing research, the current challenges faced by this method were discussed, and suggestions for specific implementation strategies were put forward. **Results** LL-BFR training, through mechanisms such as hormone secretion and protein synthesis, can achieve effects similar to high-intensity training, significantly enhancing muscle strength and quality in the elderly, and to some extent, improving vascular function. However, this method still poses safety concerns, such as adverse reactions including vascular diseases and muscle injuries. In the design of the program, it is necessary to pay attention to the optimization of pressure and training parameters. **Conclusion** As a novel and well-tolerated approach, LL-BFR training has great potential in the prevention and treatment of sarcopenia and is expected to become an alternative to traditional exercise. Nevertheless, its clinical application currently faces certain limitations and potential risks, thus requiring personalized program development and implementation under scientific guidance.

Keywords: sarcopenia; low-load blood flow restriction training; resistance training; elderly

随着全球人口老龄化趋势的加剧, 老年健康问题日益凸显,老年综合征的发病率逐年攀升,肌少症(Sarcopenia)是其中常见病症之一。肌少症作为一种与年龄密切相关的进行性、全身性肌肉数量减少和/或肌力下降及生理机能衰退的老年综合征,已成为影响老年人生活质量及寿命的重要因素[1]。肌少症不仅导致老年人活动能力受限、跌倒风险增加,还常与低骨密度、代谢紊乱以及多种慢性疾病相关联,显著提高了老年人残疾、住院及死亡的风险,给家庭和社会带来沉重负担[2]。鉴于肌少症的复杂性和多因素致病机制, 传统的康复训练往往受限于患者的体力和耐力水平, 这在一定程度上制约了康复效果的最大化。因此,探索有效的肌少症康复手段,对于提升老年人健康水平具有重要意义。

作为一种新型训练方法,低负荷血流限制训练(Low-Load Blood Flow Restriction Training,LL-BFR)近年来在肌少症康复领域展现出其独特优势。LL-BFR 训练利用加压装置对肢体近

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端施加适度压力,限制运动肌群血流量,从而在低负荷运动状态下即可达到高强度训练的效果[3-4]。研究表明低负荷血流限制训练在改善老年人肌肉功能、增强肌肉力量方面效果显著,尤其适用于因年龄、疾病等因素导致高强度训练受限的肌少症患者,可有效缓解因肌少症导致的活动障碍、跌倒风险增加等问题,提高老年人群的生活质量[5-12]。然而,LL-BFR 训练在肌少症康复中的应用仍处于探索阶段,其作用机制、长期效果、训练方案、潜在风险和安全性等问题仍需深入探讨。

因此,本文旨在梳理低负荷血流限制训练在老年肌少症康复中的应用现状,探讨其作用机制、临床效果、实施策略及目前所面临的问题,以期为老年肌少症患者的康复提供理论指导,为后续的临床实践和科研工作提供有价值的参考。

1　肌少症的概述

1.1　肌少症的定义与流行病学

肌少症(Sarcopenia)是一种以肌肉力量、质量和身体功能下降为特征的进行性骨骼肌疾病,在 1989 年由 Rosenberg 首次提出[13]。亚洲肌少症工作组指出,肌少症为“与年龄相关的骨骼肌质量损失和/或肌肉力量损失和/或身体功能表现下降”,并被欧洲老年人肌少症工作组(European Working Group on Sarcopenia in Older People,EWGSOP)定义为一种与衰老相关的进行性和全身性骨骼肌疾病[14-15]。在 EWGSOP 提出的指南中,肌肉力量、肌肉数量或质量以及身体功能表现是诊断肌少症的 3 个主要指标,并将肌肉力量(主要通过握力测量)作为肌少症评估的首要参数,肌力是目前衡量肌肉功能的最可靠指标,而身体功能表现可用于肌少症严重程度的评价[15]。

目前,全球肌少症患者高达 5 000 万人,预计在 2050 年将达到 5 亿人,60 岁以上人群的患病率约为 10%~27%[16-18]。在亚洲,老年肌少症患病率估计为 4.1%~12.3%[19-20]。在中国农村地区老年男性肌少症的患病率为 6.4%,老年女性为 11.5%,其中年龄是重要因素,而糖尿病、消化性溃疡和饮酒习惯等其他因素会提高肌少症的患病率[19]。

1.2　肌少症的影响因素

目前认为肌少症的发生和发展是多因素共同作用的结果。其中,年龄是肌少症最重要的危险因素,肌少症在老年人群中普遍存在,而营养摄入不足、缺乏运动、用药、不良的生活习惯、情绪以及基础疾病等因素也与肌少症密切相关[14-15,21]。此外,肌少症患者往往易伴有一种或多种合并症,如糖尿病、高血脂、骨质疏松症、心脏病、慢性呼吸系统疾病、恶性肿瘤、认知障碍以及肌少性肥胖等[14,17,21-24]。这不仅会增加患者跌倒、骨折的风险,还限制了日常生活活动能力,导致生活质量下降,提高了住院风险及治疗费用,甚至造成残疾和死亡等不良结局的发生,为个人、家庭及社会带来了较为沉重的负担[25-29]。

1.3　肌少症的运动干预

运动干预是预防和治疗肌少症最为经济有效的手段之一,可以减少老年人跌倒、骨折等风险的发生[30-34]。其中,抗阻运动是老年肌少症患者首选的运动方式,在改善患者肌肉力量、肌肉质量和身体功能方面具有明显的优势[35-39]。研究发现,短期抗阻训练可以提高骨骼肌蛋白质合成率,持续的抗阻训练能够明显增加握力和瘦体重[40-41]。此外,有氧运动(如慢跑、骑车、游泳等)可以提高心肺能力,加强骨骼肌线粒体的功能,推动肌肉毛细血管化,有利于提升营养物质的输送效率,进而加速肌原纤维蛋白的合成,提高肌肉耐力水平,但对增强肌肉力量和质量的效果有限[39,42-43];平衡训练和柔韧性训练可作为辅助训练在其他运动前后进行,优化老年人的整体身体状况,提高运动过程中的安全性,并减少潜在的不良反应[33];组合运动(抗阻联合有氧运动、抗阻联合平衡训练等)因具有较好的全面性、依从性,也逐渐被应用于肌少症的防治中[38-39,44];全身振动训练可以通过机械振动刺激本体感受器,引发神经肌肉反应,改善肌肉协调性,增加肌肉力量,提高肌肉的收缩效率以及爆发力,从而提升肌少症的治疗效果[45]。

与其他运动形式相比,抗阻运动尤其是中高强度抗阻运动对肌肉的改善效果更为明显[33,36,46-47]。但肌少症患者由于年龄、合并症等因素可能无法承受训练中的高负荷强度,患者的依从性较低,易造成肌肉骨骼系统损伤及不良反应,增加发生不良事件的风险。因此,老年肌少症患者的运动干预应以安全为前提,开展更具有针对性、有效性的训练方法。

2　低负荷血流限制训练的作用机制

低负荷血流限制(LL-BFR)训练是一种特殊的训练手段,通过应用加压装置(如弹力带、加压袖带等)对肢体近端进行适度的外部加压,限制运动时的静脉血液回流,同时部分阻断动脉血流,减少肌肉组织的血流量,从而在低负荷运动状态下达到高强度训练的效果,提升肌肉代谢水平,促进肌肉组织生长与恢复,达到快速增加肌肉体积、提升肌肉力量、提高耐力的目的[3-4]。这种训练方式不仅能减轻传统高负荷抗阻训练带来的身体负担,还能够针对患者的特定需求,提供个性化的康复方案,为老年肌少症患者提供了一种安全、高效的康复途径。

LL-BFR 训练在提升肌肉质量和功能方面可能的作用机制主要包括:1)激素分泌:LL-BFR 训练能够通过限制血液流动,增加肌肉代谢物的积累,从而刺激合成代谢反应,导致生长激素和类胰岛素样生长因子的分泌增加,这些激素在肌肉生长过程中起着关键作用[48-50];2)蛋白质合成:LL-BFR 训练能够激活 mTOR 信号通路,可参与调控 mRNA 翻译起始和蛋白质合成,同时这种训练方法可增加核糖体 S6 激酶 1 的活性,进而加快蛋白质的合成速率,减少细胞中的蛋白质水解,促进肌肉生长[51-53];3)肌纤维募集:LL-BFR 训练诱导的低氧环境可以有效地募集和激活更多的肌纤维,特别是快肌纤维(Ⅱ型肌纤维),类似于高强度训练的效果,长期进行 LL-BFR 训练还可能使肌肉产生适应性变化,如肌纤维类型的转变和肌纤维横截面积的增加;4)骨骼肌血流量增加:LL-BFR 训练可以通过短暂限制骨骼肌血流引起缺血反应,进而增加骨骼肌血流量,使肌肉反应性充血导致肌肥大[54-55];5)卫星细胞增殖:LL-BFR 训练能够促进卫星细胞的增殖,进而可能在骨骼肌的生长和再生中发挥积极的作用[56-58]。

综上所述,LL-BFR 训练通过多种机制协同作用,能够在较低的运动负荷下达到与高强度抗阻训练相类似的肌肉适应和提升效果,为肌少症患者提供了一种有效的训练手段。

3　低负荷血流限制训练在老年肌少症患者中的应用效果

LL-BFR 训练是一种更可靠、更新型的运动方式,对肌少症患者的康复具有显著作用,能够增加肌肉体积,提高肌肉力量和肌肉质量,改善血管功能,且不会增加老年人受伤风险,最终可达到与传统的高强度抗阻训练相似的效果。但目前 LL-BFR 训练也存在一些局限性和不良反应,需要对 LL-BFR 训练的潜在风险和安全性进行深入探讨。

3.1　对骨骼肌的影响

LL-BFR 训练可以提高肌肉力量和肌肉质量。研究表明,即使是低至 20% 1RM(重复 1 次可举起或抬起的最大重量)的运动强度的 LL-BFR 训练下也显示出有益的效果,可增加骨骼肌体积和肌肉力量[59]。Patterson 等研究显示 4 周的 LL-BFR 训练可增加老年人小腿肌肉的等长收缩力量[60]。同时,LL-BFR 训练还可增加老年女性股四头肌横截面积以及伸膝力量,且不会损伤其血管功能[61]。而 Yasuda 等发现在经过 6 周的 LL-BFR 训练上肢肌肉力量明显增强,且在停止训练 6 周后,这种力量增强效果得到了很好的保持,这可能与肌肉肥大有关[62]。LL-BFR 训练除了可以提升老年人的肌肉力量外,在改善肌肉质量方面也与高强度抗阻训练有相似的积极效果[63-66]。

3.2　改善血管功能

除了对肌肉骨骼系统的影响外,LL-BFR 训练还可以改善老年人的血管功能。Shimizu 等在对老年人进行 4 周 LL-BFR 训练后发现,其去甲肾上腺素、血管内皮生长因子和生长激素水平显著升高,反应性充血指数和足部经皮氧分压明显增高,血管性血友病因子显著下降,这提示 LL-BFR 训练可改善老年人的血管内皮功能及外周血液循环[67]。还有研究显示 LL-BFR 训练可降低血管僵硬度和提高血管顺应性[68-69]。Evans 等发现 LL-BFR 训练可以促进毛细血管的生成,从而增强微血管滤过能力[70]。Larkin 等的研究也支持这一观点,他们发现 LL-BFR 训练可增强血管生成基因的 mRNA 表达水平[71]。此外,与传统的高强度抗阻训练相比,LL-BFR 训练还可促进运动后的低血压反应[72]。然而,在 Yasuda 等的研究中却发现,经过 12 周的 LL-BFR 训练后受试者的心踝血管指数和踝臂指数均无明显变化[61]。虽然有研究证实了 LL-BFR 训练对血管功能产生了积极的作用,但由于研究的样本量较小且存在争议,目前未能阐明血流动力学改变的内在机制,因此 LL-BFR 训练对血管功能的影响有待深入探索。

3.3　潜在风险与安全性

LL-BFR 训练能够对肌少症患者发挥明显的治疗效果,同时,与其他运动形式相比,该训练的损伤风险较低[73]。由于在较低的负荷下进行训练,既达到了高强度抗阻训练的效果,又减少了训练中的机械应力,减轻了老年人的运动负荷,可降低其受伤风险。LL-BFR 训练与传统的高强度抗阻训练相比安全性和耐受性更好,提高了患者的依从性,因此适合心血管和骨骼强度较弱的老年人,尤其是肌少症患者[74-75]。

然而,由于 LL-BFR 训练会产生神经肌肉、血流动力学、代谢等方面的急性效应,使得该训练可能伴随潜在的不良反应和安全性问题,如引发血管疾病、肌肉损伤等,这也是 LL-BFR 训练在临床应用中受限的主要原因。研究显示在 LL-BFR 训练后,迟发性肌肉酸痛(39.2%)、麻木(18.5%)、昏厥/头晕(14.6%)和瘀伤(13.1%)的副作用发生率最高[76]。而 Tabata 等发现过度的 LL-BFR 训练会对肌细胞造成损害,严重时可出现横纹肌溶解的症状[77]。

除不良反应外,由于肌少症患者多合并基础疾病,该类人群在进行 LL-BFR 训练时可能存在一些潜在风险。例如,内皮祖细胞是祖细胞的一个血管生成亚群,在维持内皮完整性方面发挥着关键作用,这些细胞对运动有反应,因此运动可通过动员此类细胞在血管修复和维护中起关键作用。而 LL-BFR 训练引起的局部缺氧可能会抑制运动诱导的内皮祖细胞动员,损害了内皮完整性[78]。同时,在 LL-BFR 训练时动脉闭塞压力过高诱导血管阻塞,可能导致肌肉反射过度激活,从而使交感神经异常活跃,心功能、血压、血管阻力升高,这些在运动期间由血流限制诱发和运动加压反射介导的心血管并发症可能会增加心脑血管相关不良事件的风险(如心脏心律失常、心肌梗死、中风和心脏性猝死)[79]。

因此,在 LL-BFR 训练的实施过程中,特别是针对老年群体,仍需要更多的研究探索其对血流动力学和血管的影响机制,以证实该训练的安全性和有效性。

4　低负荷血流限制训练在老年肌少症患者中的实施策略

尽管 LL-BFR 训练展现出较大的应用潜力,但目前仍面临一些挑战,如潜在风险以及不良反应(如血管疾病、肌肉损伤)等。因此,在科学指导下针对老年肌少症患者进行个性化训练方案的制定和实施显得尤为重要。

4.1　血流限制训练的方案设计

压力参数和训练参数是 LL-BFR 训练方案中最重要的两个部分,特别是与老年肌少症患者的安全密切相关[80]。同时,袖带尺寸、加压压力(袖带加压值)、训练负荷、训练频率及组间间隔等变量会直接影响 LL-BFR 训练的干预效果。因此,压力和训练参数的优化设置尤为关键,这些要素有助于更好地确定 LL-BFR 训练方案、更好地管理肌少症及其相关合并症。

4.1.1　压力参数

LL-BFR 训练压力参数的设置主要包括袖带尺寸、加压位置、压力大小等[81]。正确选择袖带尺寸可以减少不良反应(如疼痛、疲劳),同时确保训练效果。目前有研究认为,在施加相同的动脉闭塞压下,袖带的宽度不会影响训练效果,但使用宽袖带可以在较低压力下达到动脉闭塞的效果,这不仅提高了舒适度,还确保了安全性,故建议选择较宽的袖带[81-82]。但 Rossow 等人指出,使用宽袖带会限制运动能力,并可能对心血管系统产生急性的负面影响[83]。Wernbom 等发现,四肢周长与其所需的压力大小呈正相关,这意味着下肢训练宜选用较大尺寸的袖带,而上肢则宜选用较小尺寸的袖带[84]。因此,袖带尺寸应根据四肢周长和训练部位来选择,以达到最佳训练效果。

加压位置一般位于肢体的近心端,以保证肢体大部分处于缺氧环境,并减少关节活动受限,避免神经损伤[82]。此外,LL-BFR 训练的最佳加压值因人而异,在同一个体的上下肢之间也有所差异。目前建议在 LL-BFR 训练中加压值可选择为动脉血流完全闭塞所需压力值的 40%~80%[82-83,85]。同时,有研究表明,为获得良好的训练效果,减少运动中的疼痛和损伤,在训练开始时,上肢加压值不应高于 140 mmHg,下肢加压值

不应高于 180 mmHg[86]。在训练过程中建议每 5~10 min 解除压力,再灌注 30~60 s 后继续加压[82]。首次训练应从较小的压力开始,这样不仅能够保证老年患者训练的耐受性和有效性,同时也能最大程度地减少潜在风险的发生[87]。

4.1.2　训练参数

训练参数主要包括阻力负荷、训练频率、训练时间等内容。由于肌少症与年龄相关,所以针对老年患者 LL-BFR 训练的阻力负荷一般推荐为 20%~50% 1RM，目前在这一范围内尚未发现有不良事件发生[5,82,85,88-90]。训练频率建议为每周 2~3 次,这一训练频率具有较高的安全性，且能够有效地改善肌肉力量和肌肉质量[9]。在目前针对 LL-BFR 训练的研究中,每次训练的重复次数大多为 45~75 次[91]。并不是重复次数越多越好,盲目增加训练时长或重复次数非但不能带来更好的效果,反而会导致过度训练。因此,多项研究建议每次训练进行 2~3 组,第 1 组重复 30 次,其余每组重复 15 次,组间休息 30~60 s,若患者耐受可增加 1~2 组,但每次训练不超过 5 组,训练时间持续 4~16 周[82,85,90]。

4.2　注意事项

老年人基础疾病较多，在开展 LL-BFR 训练前需明确有无禁忌证。目前已有得指南明确了血流限制训练的禁忌证包括糖尿病、深静脉血栓形成、凝血功能障碍、肾脏损害以及癌症等多种疾病[81]。但随着研究的不断深入,血流限制训练的适用人群已逐渐扩大至慢性肾病、腹部癌症等患者[92-93]。除了进行禁忌证的评估外,还需关注老年肌少症患者的皮肤状况,观察是否存在皮肤破损、红肿、瘀斑以及水疱等问题,对于皮肤状况良好的患者可进一步评估其动脉闭塞压。

由于肌少症患者容易合并骨质疏松、糖尿病、高血压等慢性疾病，在正式训练前务必进行全面的评估，包括患者的病情、爱好、经济水平等因素,以制定出个体化的训练方案,保证训练的安全有效。例如,针对肌少症合并慢性心力衰竭或慢性阻塞性肺疾病的患者,运动前的准备工作尤为重要,需详细评估患者的用药情况、心功能分级及肺功能状态,对于心功能达到 IV 级或处于急性发作期的患者,建议暂停运动,以卧床休息为主,待病情趋于稳定后再逐步引入运动训练,并循序渐进地增加运动强度[94-95]。此外,在训练过程中应尽量规避可能导致危险的动作,特别提醒合并高血压的患者避免憋气行为,并持续关注身体的即时反应。为了确保 LL-BFR 训练的安全性和有效性,建议在专业人员或康复师的指导和监控下进行,以降低不良反应及不良事件发生的风险。

5　总结

综上所述，作为一种新兴的康复手段,LL-BFR 训练在老年肌少症患者的干预中显示出巨大的潜力。现有研究表明,LL-BFR 训练通过促进激素分泌、蛋白质合成以及肌纤维募集等机制，在低负荷条件下能有效提高老年患者的肌肉力量和肌肉质量,改善血管功能,同时降低了高强度抗阻训练带来的肌肉骨骼系统损伤风险,提高了老年患者康复训练的有效性、依从性及安全性。然而,LL-BFR 训练同样也存在一些局限,如针对相关作用机制的研究不够全面，训练可能带来的不良反应和潜在风险,缺乏对长期效应的关注,老年患者训练的安全承受范围不明，没有针对老年患者的个性化训练方案等。因此,未来研究应进一步探索 LL-BFR 训练的作用机制,针对老年患者进行大样本、高质量的临床试验,探究其在临床应用中的长期效应,关注各项安全指标及可能出现的不良反应,以便制定出更适合老年肌少症患者的个性化训练方案。

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