·综述·

下肢正压支撑跑台训练:一种全新的减重训练方法

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减重(body weight support)训练就是通过各种手段减轻下肢负重,使得患者能够在一个安全载荷范围内进行训练,以达到促进组织愈合和提升功能水平的目的。减重训练是神经疾患及肌肉骨骼损伤等患者常用的康复治疗手段[1-4],传统的减重方法很多,但均存在一些缺陷。近几年来,一种具有全新减重理念的训练方式——下肢正压支撑跑台训练(lower body positive pressure supported treadmill, LBPPST)应用于体育训练及康复治疗,其先进的设计理念、前所未有的舒适性和优异的可操作性得到了广泛的认可。本文就该技术及有关的研究进展做一介绍。

传统的减重训练方法

用于减重的方法很多,如拐杖、助行器、双杠、治疗师辅助的腰带(therapist-assisted waist belts)、悬吊系统、水池等[5-6]。使用拐杖、助行器或双杠等方法简便、经济,但均需要患者增加上肢用力,造成步行时身体姿态异常,且往往会增加患者的能量消耗[7]。因此,那些上肢力量较差、多发损伤,以及因长期卧床、高龄及心血管疾病等导致运动能力低下的患者,并不适宜采用这些方法进行康复训练,且采用这些方法减重幅度既不恒定也不能量化[8];治疗师通过腰带辅助训练虽能减少患者上肢的使用,但可能明显改变患者行走时的步态。由于此方法全程需治疗师陪伴,因此并不适合于那些肥胖、身材高大、多处损伤、体弱或者高龄等患者。更重要的是,采用此方法训练,很难明确受损侧下肢的负重情况。

水中训练由于浮力的作用可有效减轻体重载荷。在齐腰至胸深的水中,减少 40% ~60% 的体重[9],深水中跑步所需的代谢能量有助于维持有氧功能[10]。水中训练的另一个优势是可利用水的阻力训练肌力。前交叉韧带重建患者进行水中训练可有效减少关节液渗出,并取得与陆地训练相似的膝关节被动活动范围及更好的功能改善[11]。然而,水中的粘滞力和浮力,可改变步态及肌肉的激活模式,并减少本体感觉和协同作用[12]。此外,细菌污染、伤口感染及伤口裂开等不利影响[13],以及高额的设备及维护费用均是选用水中训练要考虑的问题。头顶悬吊(overhead suspension harness systems)平台训练是通过一个悬吊系统提供一个单纯的垂直力,以减轻患者体重,使其能在活动平台上进行锻炼,目前在临床康复中广泛应用[2,4,9],很多的研究探讨了减重幅度对人体代谢、力学等方面的影响,以指导其临床应用[14-15]。然而,一个明显的问题就是使用时的不舒适性,可能阻碍血液循环,因而不能长时间训练。而且,悬吊带如果跨过手术或损伤的部位,可能会引起疼痛。此外,尽管利用水池及悬吊系统进行训练能粗略控制减重的程度,但很难精细、及时地进行调整,不利于制定详细可操作的训练方案[16-18],影响康复训练的贯彻和长期的坚持[17]。

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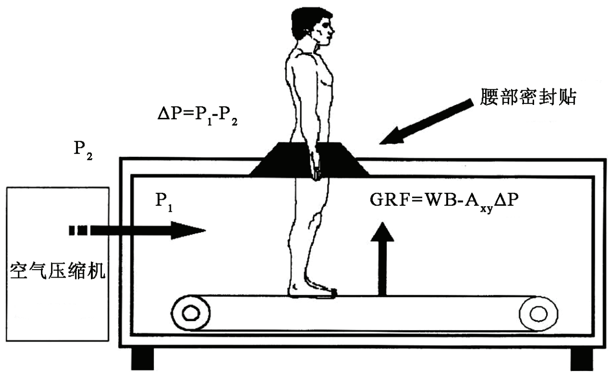
下肢正压支撑跑台训练

下肢正压支撑跑台训练系统由一个密闭的气囊和一个训练跑台组成。气囊通过一个密闭贴(airtight seal)紧贴人体腰部,使得人体的下半身处于一个密闭的环境中。通过对气囊充气形成一个下肢正压(lower body positive pressure, LBPP),气囊内、外的空气压差(advanced differential air pressure, DAP)产生一个向上的支撑力,使得人体在减重的环境下在活动平板上训练。这种设计理念最早由 Robert Whalen 博士在进行宇航员太空锻炼的生物力学研究时发明。LBPP 作用原理见图 1 所示:充气后,气囊内部的压力大于外部的压力(外部为大气压),这种压力差通过附于腰部的密闭接触区产生了一个作用于人体的垂直向上的作用力,减少了地面反应力(ground reaction forces, GRFs)。GRFs 可由下面的公式得出:$GRFs = WB\text{-}A_{xy}\Delta P$(其中 WB 是体重,$A_{xy}$为腰部密封贴的面积,$\Delta P$ 为气囊内外压力差)。气囊内较小的压力变化将导致 GRFs 明显的改变。因此,通过精细改变气囊内的压力,就可以准确地微调 GRFs 的减少量——这就是该技术的主要特点。该系统通过计算机控制,可精确控制 20% ~100% 的体重负重范围,并以 1% 的层级进行调整。这种通过控制压力差精确地调控体重支撑力大小的技术完全不同于以往使用的减重训练技术。



GRF:地面反应力;WB:体重;A_{xy}:腰部密封贴的面积;ΔP:气囊内外压力差;P_1:气囊内压力;P_2 = 气囊外压力

图 1　LBPP 作用示意图

LBPP 技术的另一个不同于其他技术的重要特点是无论支撑力的大小,其作用点与人体重力点相同或接近,这样就能提供一个平衡的支撑,并保持正常的生物力学特性。如在 LBPP 中以 50% 的支撑力行走或者跑步,就相当于模拟一个 1/2 的地心引力失重环境步行或跑步,这样外在的 GRFs 及内在的肌肉骨骼受力相应减少,但仍保持着正常的运动神经肌肉模式。此外,增加的气压以及所产生的支撑力均匀地分布于人体下部,因此,尽管体重被支撑,人体却没有明显的压力感。反观悬吊系统,其接触部位往往形成集中的压力点,因而使用舒适度远低于

LBPP,特别在高减重幅度的情况下[19],而且通过在身体周边的悬吊带产生向上的牵拉力,其作用点与重力点并不一致;水中训练时,其支撑点的位置及力的大小随水的深度不断变化不同,且水中较大的粘滞阻力将显著影响肌肉激活的模式。

LBPP 技术的力学、代谢及心血管评价

LBPP 通过支撑气囊内外的压力差对人体产生一个向上的提升力,达到减轻体重的目的。有研究表明:30 ~ 50 mmHg 左右的压力差,能减轻大约 50% ~ 90% 的人体重量[20-21]。LBPP 跑台上减重跑步时,GRF 峰值减少,且随着减重幅度的增加呈线性下降[20]。EMG 的结果也显示进行 LBPP 活动时下肢肌肉最大收缩力也随之下降[22],这将使活动时通过关节的作用力减少。GRF 峰值的大小与过度跑步损伤危险密切相关[23-24]。另一方面,LBPP 跑步时(从 60% 到 20% 体重),尽管 GRFs 下降,而膝、踝关节活动范围无明显改变[20]。因此,LBPP 支撑性跑步作为一种新型的训练及康复手段,既可减少过度使用损伤的危险,又能够保留步态力学特性。

减重训练可以通过减少作用于肌肉骨骼系统的力,使得患者能早日恢复康复训练,并防止过度运动损伤,但减重也减少了代谢需求,不利于心血管功能的恢复与提升。为此,Grabowski 等[25-26]分别探讨了步行及跑步时减重幅度和速度与代谢量的关系,发现 LBPP 训练时,可通过调整步行或跑步速度及减重幅度,达到既可以减少 GRF 及力学损伤危险,又保持足够的有氧刺激及肌肉神经功能的目的。Donaghe 等[27]也发现:在体重减轻 25% 的情况下,步行速度 3.5 mph 以内,通过增加 0.5 mph 的速度可达到同样的耗氧量;跑步速度在 9 mph 以内,增加 3 mph 的速度达到相同的耗氧量。

很多研究证实:直立体位时,LBPP 能增加静脉回流,增加心搏出量,并降低心率[28-30],这有利于减少那些有活动障碍、脊髓损伤,或手术/长期卧床后重新站立的患者发生眩晕和跌倒的危险。此外,LBPP 还可减轻下肢肿胀,促进血液循环,起到治疗作用。运动时 LBPP 对心率的影响可能取决于运动强度的大小,如运动时下肢肌肉泵及其他心血管反应所致静脉回流的作用大大高于 LBPP 本身的影响,则 LBPP 运动对心率的影响不明显[30],反之就引起其下降[20]。另一方面,站立及运动时,LBPP 对平均血压及脑耗氧量、通过中脑动脉的血流速度,以及头部皮肤微血管流量等心血管指标并无明显改变[20,29],说明 LBPP 训练并不导致心血管系统的危险,适用于伴有心血管疾患老年人的训练。此外,Ruckstuhl 等[19]曾比较了健康志愿者分别采用 LBPP 与悬吊系统减重训练在不同减重幅度及步行速度情况下的心率,发现 LBPP 组显著低于悬吊组,显示 LBPP 行走更适合于心血管患者,特别对有心血管疾病患者的早期步行训练很重要。一个重要的发现是:尽管 LBPP 对心率有影响,但部分减重并不改变运动时心率与耗氧量的关系,对自觉疲劳程度评分与心率的影响轻微[30],因此仍可以根据心率指数来判断运动负荷,以指导针对心血管功能的训练。

应　　用

一、骨科疾病康复

减重训练已广泛应用于骨科康复治疗,近年来 LBPP 技术也逐渐开始用于跟腱损伤、膝关节术后等的康复治疗[31-32]。在保护受损组织的前提下早期开展负重训练是骨科临床治疗的一个常规[33]。众所周知,制动或者不活动,将对组织愈合,甚至肢体功能的恢复产生一系列不利的影响;早期适当的训练,不仅能有效预防或减轻这些有害的影响,还能促进组织的愈合[34]。然而过大的负重往往会加重组织的损伤程度。因此,应通过减重使下肢在一个控制负荷(controlled weight-bearing)的范围内进行训练。值得注意的是:组织的愈合大致分为急性炎症期、再生修复期和重塑期三个阶段,随着愈合的进展,受损组织的形态结构及力学特性逐渐恢复,因此应不断调整减重的程度,以进行"渐进性载荷"(progressive loading)训练。由于 LBPP 可以提供一个大范围的减重环境(20% ~ 100% 体重)以及精细的调控(1% 的增减),因此,可以较其他减重系统更好地贯彻"控制负荷"及"渐进性载荷"的原则,并可以制定更精细、可操作的训练方案。此外,与水中训练相似,LBPP 能有效地减轻下肢肿胀及关节渗出液[26];与悬吊系统相比,LBPP 更适合跑步训练,因此在恢复后期,可通过跑步训练更好地提升心血管功能及肌肉耐力。

二、神经系统疾病所致下肢功能障碍的康复

此类患者不能自行站立、行走,或者以异常模式行走,很多学者发现减重训练能更好地改善偏瘫患者的步态并提高运动能力[3-4],甚至被推崇为最有效的脑卒中步态训练技术[35]。神经生理证据表明:早期平台行走训练能增强神经可塑性活动[36-37],刺激下肢的本体感受器,激发脊髓中的运动启动点,使下肢各组肌群协调运动,从而提高下肢活动能力[38]。此外,由于减重使得患者在步行中身体重心的分布趋于对称,有利于提高其行走的稳定性及恢复正常的步行模式;而且患者在减重装置的保护下,安全性有了保障,可减轻行走中的紧张和恐惧心理,获得更好的治疗效果。近年来,LBPP 技术开始用于脑瘫、帕金森氏病等[39-40]患者的康复治疗。与悬吊系统相比,其舒适性使得患者可以维持较长时间的训练,并可以根据患者的感受及时调整负重幅度。

三、其他人群的有氧训练

与其他的减重技术相比,LBPP 技术另一个明显的优势在于其更适宜于跑步训练。独特的减重与跑步训练相结合为很多人群提供了一个无可替代的有氧训练手段。肥胖日益成为一个世界范围的严重社会问题。体重超重是膝关节骨性关节炎(osteoarthritis, OA)发生的重要危险因素[41],有研究显示 5% 的体重下降能显著改善因 OA 所致的功能障碍[42]。为达到减轻体重的目的,很多的专业指南推荐中到高强度的运动[43-44],然而肥胖者由于体重负荷大、运动水平低往往无法达到所推荐的运动量,甚至由于关节疼痛等症状根本无法进行锻炼。一项针对 LBPP 技术的研究表明:12.3% 左右的体重支撑,能显著减轻膝 OA 疼痛,并保证舒适的锻炼[45]。更重要的是,通过 LBPP 减重训练能使肥胖者完成所需强度的跑步训练,减少游离脂肪量,获得有意义的卡路里消耗[46]。

跑步速度的增加,将直接导致代谢能量需求的增加。运动员常需通过加快跑步速度来增加代谢量,以提高训练水平、心血管功能及神经肌肉功能,并帮助提高肌肉力量。然而,快速跑步往往不能持久,并有增加运动损伤的风险。而采用 LBPP 技术就可以在保证安全的情况下加快跑步速度,有利于运动水平的

提升。另一类特殊人群是老年人:由于全身功能减退,老年人存在心血管功能低下、肌力下降、平衡功能差、组织抗损伤阈值低等一系列问题,并常伴有膝 OA 及关节疼痛。老年人采用 LBPP 减重训练,不仅可以提供体重支撑,减轻运动时的疼痛,减少过度运动损伤,提高心血管功能;而且由于该技术还能提供水平和侧方的保护力,保证使用者的平衡,有利于老年人安全、有效的有氧训练。

结 语

作为一种全新的减重训练技术,LBPP 以其独特的设计理念提供了一个其他减重技术无法比拟的舒适、方便的训练平台。该技术在力学、代谢及心血管反应等方面令人鼓舞的研究结果,使得此项技术在临床康复及体育训练等方面中的应用日益广泛。然而作为一项新型的训练技术,需通过临床实践,制定出针对不同疾病和不同人群精细的训练方案,为更有效利用 LBPP 减重技术进行训练和康复提供指导。

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Timing of physical therapy referrals for low back pain

BACKGROUND AND PURPOSE: Low back pain (LBP) accounts for 2.5% to 3% of all physician visits in the United States. Despite increasing expenditures, the prevalence of chronic, disabling LBP is increasing. This study examined the impact of timing and content of physical therapy referrals on the utilization costs of healthcare. **METHODS**: This retrospective study used the Mercer Health Online database for patients aged 18 to 60 years with a primary diagnosis of LBP. Of these patients, seven percent received physical therapy. The timing of the start of therapy after the initial diagnosis was noted, with subjects divided into those with early referrals (within 14 days) and late referrals (15 to 90 days). The treatment during the physical therapy visit was categorized as active, if more than 75% sessions were active (therapeutic exercise, self-training management), or passive, if fewer than 75% of the sessions were active. The participants were followed for 18 months, with healthcare utilization costs calculated. **RESULTS**: A total of 76,967 eligible patients with a primary care visit for LBP within the study period were identified, of whom 32,070 (41.7%) were included in the study. The subjects receiving early physical therapy were less likely to undergo advanced imaging, additional physician visits, major surgery or lumbar spine injections, or to be treated with opiates, as compared to those whose therapy referrals were delayed. Total medical costs for LBP management in patients receiving early PT were $2,736.23 less than that for those receiving late referrals. Patients receiving active physical therapy were less likely to receive surgery or lumbar spine injections with medical expenses found to be $1,374 less when compared to the passive group. **CONCLUSION**: This retrospective study of patients with low back pain found that referral to physical therapy within two weeks of physician consultation is associated with a reduced risk of subsequent healthcare utilization and lower, overall health care costs.

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