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多酚与植物蛋白在肌肉减少性肥胖防治中的研究进展

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摘　要

肌肉减少性肥胖(Sarcopenic Obesity, SO)是一种以骨骼肌质量、力量和(或)功能下降并伴脂肪异常积累为特征的代谢性疾病。SO不仅显著增加跌倒、骨折及活动受限的风险，还与全因死亡率升高及医疗资源负担增加密切相关。随着全球人口老龄化加速及肥胖率持续上升，SO的发病率呈逐年增长趋势，已成为重要公共卫生问题。近年来，营养干预作为SO预防和治疗的重要策略，受到广泛关注。多酚类化合物因其抗氧化和抗炎特性，能够改善代谢稳态及肌肉功能；植物蛋白则通过提供必需氨基酸及其代谢产物，促进肌肉蛋白合成，有助于优化身体组成、增强肌肉力量及提升功能表现。此外，多酚与植物蛋白之间存在相互作用，影响营养素的消化吸收及生物利用度，且可能产生协同效应。然而，现有研究多集中于单一营养成分的作用，二者的联合作用及其机制尚未明确。本文综述了多酚与植物蛋白质在SO防治领域的研究进展，探讨其潜在作用机制，旨在为营养干预策略的制定及临床实践提供理论依据。

关键词

肌肉减少性肥胖，多酚，植物蛋白，营养干预

Research Progress on Polyphenols and Plant Proteins in the Prevention and Treatment of Sarcopenic Obesity

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Abstract

Sarcopenic obesity (SO) is a metabolic disorder characterized by the decline in skeletal muscle mass, strength, and/or function accompanied by abnormal fat accumulation. SO not only markedly increases the risks of falls, fractures, and functional limitations, but is also closely associated with higher all-cause mortality and greater healthcare burden. With global population aging accelerating and obesity prevalence continuing to rise, the incidence of SO has been increasing annually and has become an important public health concern. In recent years, nutritional interventions have gained increasing attention as key strategies for the prevention and treatment of SO. Polyphenols, owing to their antioxidant and anti-inflammatory properties, can improve metabolic homeostasis and muscle function, whereas plant proteins, by providing essential amino acids and their metabolites, promote muscle protein synthesis and contribute to optimizing body composition, enhancing muscle strength, and improving physical performance. Furthermore, interactions between polyphenols and plant proteins may influence nutrient digestion, absorption, and bioavailability, potentially leading to synergistic effects. However, most current studies have focused on the effects of single nutrients, and the combined effects and underlying mechanisms of polyphenols and plant proteins remain to be clarified. This review summarizes recent advances in research on polyphenols and plant proteins in the prevention and management of SO, explores their potential mechanisms, and aims to provide theoretical evidence for nutritional intervention strategies and clinical practice.

Keywords

Sarcopenic Obesity, Polyphenols, Plant Proteins, Nutritional Intervention

1. 引言

肌肉减少性肥胖(Sarcopenic Obesity, SO)是指在肥胖基础上伴随骨骼肌质量、力量和(或)功能下降的一种复杂代谢性疾病[1]。随着全球人口老龄化加速及肥胖流行趋势的持续上升，SO 的患病率逐年增加，已成为全球公共卫生关注的重点之一[2]。流行病学研究显示，SO 影响全球约 10%的老年人群(60 岁以上)，且随年龄增长显著升高，在 75 岁及以上人群患病率中可达 23% [3]。SO 不仅增加跌倒、骨折和活动受限等功能损害的风险，还与代谢性疾病发生率升高及全因死亡率增加密切相关[4]-[6]，对老年人生活质量和社会医疗负担产生深远影响[7] [8]。SO 的发生受多种因素影响，包括年龄相关的肌肉衰退、慢性低度炎症、胰岛素抵抗以及不良生活方式等[9]-[11]。

鉴于生活方式和饮食因素在 SO 的发生与防治中发挥着关键作用，近年来营养学干预逐渐成为研究热点。研究显示，饮食营养在维持肌肉质量和功能中起重要作用，其中多酚和植物蛋白被认为是当前较受关注的营养干预因子。多酚具有抗氧化、抗炎及改善代谢稳态的作用[12] [13]。而植物蛋白能够为肌肉蛋白合成提供必需氨基酸，并支持肌肉代谢平衡[14]。已有研究提示，这两类营养因子可能通过多种途径，包括肠道菌群调节，进一步影响肌肉功能和代谢健康[15]。因此，探讨多酚和植物蛋白在 SO 防治中的作用及其潜在机制，对于揭示营养干预的新策略具有重要意义，这不仅可为老年人肌肉健康管理提供科学参考，也为慢性代谢性疾病的预防与干预提供新的思路。

2. 肌肉减少性肥胖(SO)病理机制概述

肌肉减少性肥胖(SO)的核心机制在于脂肪组织和骨骼肌之间形成的恶性循环[16]。当脂肪组织过度扩张时，其功能会出现紊乱，分泌大量促炎因子(如 TNF-α、IL-6)以及失衡的脂肪激素(瘦素升高、脂联素下降)，这些物质通过血液影响骨骼肌，抑制胰岛素信号通路，导致肌内脂肪沉积和线粒体功能受损，同时加速肌肉蛋白分解[6] [17]。肌肉功能下降后，又会分泌异常肌因子(如肌生长抑制素升高)，进一步加重脂肪组织的炎症和代谢紊乱，使恶性循环不断扩大[18]。这种循环会受到多种因素影响，包括激素下降(生长激素、IGF-1 和性激素减少)、氧化应激(线粒体 ROS 积累)、肌纤维类型改变(II 型快肌纤维萎缩)以及基因和表观遗传调控异常(如 miRNA 失调、BDNF 甲基化) [19]。最终，肌肉质量和力量显著下降，同时增加代谢综合征、心血管疾病及全因死亡风险。

3. 多酚与植物蛋白对肌肉健康的作用

3.1. 多酚类物质对肌肉健康的作用

多酚是植物中广泛存在的次级代谢产物，主要包括黄酮类(如槲皮素、儿茶素)、酚酸类(如咖啡酸、阿魏酸)、鞣花单宁类(如原花青素)及花青素类(如蓝莓花青素)等[20]。这些亚类可通过抗氧化、抗炎、代谢调控、线粒体功能改善及“肠道–肌肉轴”等多途径影响肌肉健康[21]。黄酮类在运动诱导的肌肉损伤防护与恢复中作用明显。例如，槲皮素可通过抑制氧化应激和下调炎症因子(IL-6, TNF-α)减轻肌肉微损伤并改善关节活动度[22]；儿茶素则通过激活 PI3K/Akt 信号通路促进肌肉蛋白合成，同时抑制 NF-KB 通路，降低炎症水平，从而加速高强度训练后的肌肉恢复[23]。花青素类在老年肌少症中的应用显示出潜在益处。一项 Meta 分析显示，每日摄入 100~300 mg 花青素可显著降低体重及脂肪量，但对肌肉质量改善效果有限，提示需结合阻力训练或蛋白质补充以增强效果[24]；此外，原花青素 C1 (Procyanidin C1)在衰老小鼠实验中可改善运动功能、平衡能力、运动耐力及肌肉力量，可能通过抑制蛋白降解、增强线粒体功能和调节代谢发挥作用[25]。总体而言，多酚通过多机制协同作用，有助于维持肌肉质量、增强肌力并改善身体功能，为预防肌少症及运动相关肌肉损伤提供潜在营养干预策略。

3.2. 植物蛋白对肌肉健康的作用

植物蛋白作为可持续的膳食蛋白来源，主要包括大豆蛋白、豌豆蛋白、米蛋白、玉米蛋白、小麦蛋白及其混合形式(如大豆、豌豆和米相组合)，其通过提供优质氨基酸、刺激肌肉蛋白合成(MPS)、增加瘦体质量及增强肌力，对肌肉健康发挥积极作用。大豆蛋白作为优质植物蛋白，可通过激活 Mtor (Mechanistic target of rapamycin)信号通路显著促进 MPS，同时改善血脂谱并降低 LDL 水平，对肌少症预防具有潜在优势[26]。豌豆蛋白在运动训练中可增加肌肉厚度和力量，其效果在一定条件下可与乳清蛋白相当[27]。米蛋白可能通过激活 Nrf2 通路增强内源性抗氧化防御，从而保护肌肉细胞免受氧化应激损伤[28]。玉米蛋白虽然亮氨酸含量相对较低，但其玉米醇碱成分具有抗氧化特性，动物实验显示每日补充可降低乳酸积累并改善运动表现[29]。混合植物蛋白通过互补必需氨基酸，可进一步增强肌肉蛋白合成潜力、改善身体组成，并在结合阻力训练或其他运动干预时对肌肉质量和力量的维持有积极作用。然而，目前仍缺乏长期人群随访数据来量化其在肌少症预防中的具体效果[30]。总体而言，植物蛋白在合理剂量与训练干预结合下，可有效改善肌肉量、肌力及身体组成，为预防肌少症和提升运动表现提供营养策略。

3.3. 多酚与植物蛋白的联合效应对肌肉健康的作用

近年来，研究者关注到多酚与植物蛋白联合摄入对肌肉健康的潜在益处。已有研究表明，绿茶儿茶

素与大豆分离蛋白联合摄入，并结合抗阻训练，可显著提升小鼠的肌肉质量和运动耐力，同时降低运动引起的氧化损伤和肌肉损伤指标[31]。此外，富含多酚的植物蛋白补充剂通过重塑肠道微生物群，增强抗氧化酶活性，显著减轻老年小鼠的骨骼肌丢失，并改善肌肉功能[32]。然而，目前的研究多集中于动物模型，缺乏长期人群干预数据。因此，未来的研究应关注其在不同人群中的效果和安全性，以为肌少症及运动相关肌肉损伤的营养干预提供更有力的科学依据。

4. 多酚与植物蛋白调控 SO 的潜在机制

4.1. 抗氧化与抗炎作用

多酚和植物蛋白均具有抗氧化和抗炎功能，对肌肉健康具有重要影响。多酚能够清除体内活性氧，降低自由基对肌肉细胞的损伤，并通过增强超氧化物歧化酶(SOD)、谷胱甘肽过氧化物酶(GSH-Px)和过氧化氢酶(CAT)等抗氧化酶活性，提高细胞自身防御能力[33]-[35]。同时，多酚可抑制 NF-KB 和 MAPK 等促炎信号通路，减少 TNF-α、IL-6 等炎症因子的产生，并降低环氧合酶(COX)和脂氧合酶(LOX)介导的炎症介质释放，从而减轻慢性炎症反应[36]-[38]。植物蛋白也表现出一定抗炎潜力，能够降低体内促炎因子水平，辅助维持肌肉细胞微环境的稳定。这些抗氧化和抗炎作用相互促进：减少氧化应激可以阻断炎症信号，而抑制炎症又能降低免疫细胞产生的活性氧，从而打破“氧化–炎症循环”[39]-[42]。通过这种多层次调控，多酚和植物蛋白为维持肌肉健康、延缓肌肉损伤提供了潜在保护作用。

4.2. 对肌肉蛋白合成与代谢的影响

多酚和植物蛋白对肌肉蛋白的合成与代谢具有重要作用。多酚能够改善肌肉细胞的能量代谢，增强线粒体功能，并通过抑制肌肉蛋白分解相关通路，帮助维持肌肉质量[43] [44]。研究发现，多酚能够降低肌肉蛋白分解因子的表达，延缓肌肉蛋白流失[45]。植物蛋白富含支链氨基酸，尤其是亮氨酸，能够有效刺激肌肉蛋白生成，提高蛋白质利用效率[46]。适量补充植物蛋白可增加肌肉量，并在一定程度上改善肌肉力量和运动功能，尤其对老年人和肌肉流失风险较高的人群尤为重要[47]。此外，植物蛋白提供的必需氨基酸可直接参与肌肉蛋白的合成过程，为维持肌肉结构和功能提供基础物质保障。总体来看，多酚通过维持细胞代谢和抑制蛋白降解，植物蛋白通过提供关键氨基酸促进蛋白生成，两者在不同环节对肌肉蛋白代谢发挥作用，为肥胖性肌肉衰减症的预防和干预提供理论依据。

4.3. 肠道菌群介导的作用

多酚和植物蛋白能够通过肠道菌群调节机体的能量代谢和肌肉功能。在肠道内，多酚可改善菌群组成，促进有益菌生长，并增加短链脂肪酸(SCFAs)如乙酸、丙酸和丁酸的生成，这些代谢产物不仅为肠上皮细胞和外周组织提供能量，还可能参与肌肉蛋白合成和代谢调节[48] [49]。植物蛋白在肠道中被微生物发酵后，产生支链氨基酸及其代谢物，这些产物能够为肌肉蛋白合成提供原料，并通过改善肠道环境促进肌肉代谢[50] [51]。已有研究表明，某些益生菌可以利用蛋白质代谢生成丁酸等产物，这不仅增强肠道的能量供应，还可能通过影响炎症水平和代谢信号间接调控肌肉功能[52]。Chang 等人的研究提示，植物源性多酚富集蛋白补充剂的摄入可能通过调节肠道菌群和增强抗氧化能力，间接改善肌肉健康[32]。与此同时，这种作用可能有助于减缓肌肉流失、维持肌肉力量及改善运动功能，对老年人或肥胖性肌肉衰减症患者尤其重要。在营养干预实践中，合理搭配多酚和植物蛋白的饮食或补充剂，不仅可以优化肠道菌群结构和代谢产物生成，还可能通过改善“肠道–肌肉轴”功能为肌肉健康提供多层次支持。这些研究为未来针对肥胖性肌肉衰减症的个体化营养策略提供了理论依据，同时提示肠道菌群在营养干预中的关键作用值得进一步探索。

5. 临床与转化应用前景

近年来，多酚–蛋白质复合物逐渐成为食品科学与营养学研究的研究热点。这类复合物不仅能够增强抗氧化能力，还可通过改变蛋白质高级结构改善其功能特性，其性质受多酚的分子量、构型及疏水性等因素影响[53] [54]。相关研究表明，多酚与大豆分离蛋白结合后，可显著改善自由基清除能力，例如茶多酚与大豆分离蛋白结合后抗氧化活性增强，为功能性食品开发提供潜在价值[55]。进一步研究显示，经碱处理的大豆蛋白–原花青素复合物抗氧化性能可进一步提升[56]，而大豆蛋白–葡萄籽原花青素复合物虽然抗氧化能力略低于游离多酚，其稳定性随时间延长而提高，长期储存中仍能有效清除自由基[57]。此外，多酚的加入可改善蛋白质构象、增强界面活性、稳定油/水界面并抑制脂质氧化，同时改善质构并掩盖不良风味，为功能性食品和饮料开发提供新策略[58]。综上所述，多酚–蛋白质复合物在提高抗氧化性能、优化食品功能特性以及潜在的营养干预应用方面具有广阔前景。

6. 总结与展望

现有研究表明，多酚可能通过抗氧化、抗炎以及改善代谢稳态来维持肌肉健康，而植物蛋白则通过提供优质氨基酸、增加瘦体重和提升肌力，从而降低 SO 的风险。需要关注的是，两者的联合摄入能够形成多酚–蛋白复合物，进一步增强对肌肉质量、身体组成及代谢健康的综合保护效应。这为肌肉减少性肥胖的营养干预策略提供了更具潜力和可行性的方向。未来研究可以考虑设计随机对照试验，比较不同植物蛋白来源(如富含支链氨基酸的豌豆蛋白或富含异黄酮的大豆蛋白)对 SO 患者肌肉质量、肌力及功能的影响，以更全面地评估其潜在效果。同时，采用析因设计探讨多酚与植物蛋白的独立及协同作用，有助于揭示两者在改善肌肉健康和代谢稳态中的相互作用机制。结合血清代谢产物分析，甚至肠道菌群测序，也可能帮助理解宿主–微生物相互作用在营养干预中的作用。长期前瞻性队列研究则可进一步评估富含多酚与植物蛋白的膳食模式对 SO 发生、进展及相关健康结局的影响。总体来看，这些研究方向不仅有助于丰富 SO 干预的科学证据，也为制定更具针对性和可行性的精准营养策略提供理论基础，同时指导临床和社区层面的实践应用。

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