

骨质疏松症与肌少症相关性研究进展

李云杰¹, 高卢婧², 何 娜¹, 胡李男^{2*}

¹吉首大学株洲临床学院放射科, 湖南 株洲

²中南大学湘雅医学院附属株洲医院放射科, 湖南 株洲

收稿日期: 2025年12月15日; 录用日期: 2026年1月8日; 发布日期: 2026年1月21日

摘 要

骨质疏松症与肌少症作为老年人群高发的退行性疾病, 已构成全球性公共健康挑战。两者常相互共存形成“骨肌减少症”, 显著增加老年人跌倒、脆性骨折、病残及死亡风险, 其协同危害远超单一疾病。骨骼与肌肉作为功能整体的“骨-肌单位”, 共享多重风险因素与病理机制。本文系统梳理了骨质疏松与肌少症相关性的研究进展, 从流行病学关联、病理生理机制、临床结局表现及综合治疗策略四个维度展开深入阐述, 最后总结当前研究现状并展望未来方向, 为临床实践中骨肌健康的协同评估与干预提供全面的学术参考。

关键词

骨质疏松症, 肌少症, 骨肌减少症, 病理生理机制, 综合治疗

Advances in the Correlation between Osteoporosis and Sarcopenia

Yunjie Li¹, Lujing Gao², Na He¹, Linan Hu^{2*}

¹Department of Radiology, Zhuzhou Clinical College, Jishou University, Zhuzhou Hunan

²Department of Radiology, Zhuzhou Hospital Affiliated to Xiangya School of Medicine, Central South University, Zhuzhou Hunan

Received: December 15, 2025; accepted: January 8, 2026; published: January 21, 2026

Abstract

Osteoporosis and sarcopenia, as prevalent degenerative diseases in the elderly population, have become a global public health challenge. The two conditions often coexist to form osteosarcopenia, which significantly increases the risks of falls, fragility fractures, disability and mortality in older adults, and their synergistic harms far outweigh those of either disease alone. As a functional unit

*通讯作者。

文章引用: 李云杰, 高卢婧, 何娜, 胡李男. 骨质疏松症与肌少症相关性研究进展[J]. 临床医学进展, 2026, 16(1): 1996-2005. DOI: 10.12677/acm.2026.161252

termed the “bone-muscle unit”, bone and muscle share multiple risk factors and pathological mechanisms. This paper systematically reviews the research progress on the correlation between osteoporosis and sarcopenia, and elaborates on it from four dimensions: epidemiological association, pathophysiological mechanism, clinical outcome manifestations and comprehensive treatment strategies. Finally, it summarizes the current research status and prospects future directions, providing a comprehensive academic reference for the collaborative assessment and intervention of bone and muscle health in clinical practice.

Keywords

Osteoporosis, Sarcopenia, Osteosarcopenia, Pathophysiological Mechanisms, Comprehensive Treatment

Copyright © 2026 by author(s) and Hans Publishers Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

1. 引言

1.1. 研究背景

人口老龄化进程的加速使老年退行性疾病的公共卫生负担日益加重，其中骨质疏松症与肌少症因其高发病率、高致残率成为关注焦点[1]。骨质疏松症以骨量流失、骨微结构破坏为核心特征，直接导致骨强度下降与骨折风险升高[2]；肌少症则表现为骨骼肌质量、力量及功能的进行性衰退，是老年人体力下降、活动受限的重要诱因[3]。临床实践与流行病学研究均证实，这两种疾病并非孤立存在，而是常以“骨肌减少症”的共病形式出现，形成 $1 + 1 > 2$ 的健康危害效应[1]。

然而，针对这一具有重要临床意义的共病关联，现有相关综述多碎片化、缺最新证据与协同视角。本文以“流行病学 - 机制 - 结局 - 干预”全链条整合，深化骨肌单位交互机制，聚焦临床协同干预方案，破解骨肌减少症分治难题，提供实用学术参考。

1.2. 研究现状与意义

骨骼与肌肉在发育过程、生理功能及病理生理进程中存在紧密关联，共同构成“骨 - 肌单位”这一功能整体[4]。两者共享遗传易感性、内分泌失调、慢性炎症、氧化应激、营养不良及体力活动减少等多重风险因素[5]。近年来，随着对肌肉因子、骨因子等生化信号通路及机械力学交互作用的研究深入，骨质疏松与肌少症的相互调控机制逐渐清晰[3]。2022 年《肌少 - 骨质疏松症专家共识》明确将骨肌减少症定义为肌少症与骨质疏松症并存的退行性代谢综合征，强调其共同的发病基础[1]。

系统梳理两者相关性的研究进展，对于完善疾病诊断体系、优化干预策略具有重要学术价值与临床意义。目前，相关研究已覆盖流行病学关联验证、病理机制解析、临床结局评估及综合管理探索等多个层面，但仍存在机制研究深度不足、个体化干预方案缺乏等问题。本文基于现有研究证据，从多维度系统综述骨质疏松与肌少症的相关性，为后续研究与临床实践提供参考。

2. 流行病学关联

2.1. 骨质疏松症与肌少症的双向流行病学关联

大量观察性研究、系统评价及荟萃分析已证实，骨质疏松症与肌少症之间存在显著的双向关联，一

方的存在会显著增加另一方的发病风险。

一项 2025 年发表的系统评价与荟萃分析纳入 14 项研究, 涵盖 182,307 名老年人, 结果显示肌少症患者发生骨质疏松症的风险显著升高($OR = 3.16$, 95% $CI: 2.47 \sim 4.02$) [6]。该研究同时揭示了明显的人群异质性: 男性患病风险($OR = 4.74$)高于女性($OR = 3.46$), 欧洲人群($OR = 4.37$)风险高于亚洲与美洲人群[6], 这种差异可能与遗传背景、生活方式、医疗保健水平等因素相关。

多项横断面研究进一步验证了这一关联。一项基于美国国家健康与营养调查(NHANES) 1999~2020 年数据的研究($n = 116,876$)显示, 在调整年龄、性别、生活习惯等多个混杂因素后, 骨质疏松症仍是肌少症的独立风险因素($OR = 4.57$, 95% $CI: 1.47 \sim 14.22$) [7]。另一项针对 262 名髌部骨折女性的研究采用欧洲老年人肌少症工作组(EWGSOP2)标准诊断, 发现肌少症患者发生骨质疏松症的校正后比值比为 2.30 (95% $CI: 1.27 \sim 4.14$) [8]。此外, 一项纳入 484 名社区老年人的研究则显示, 骨质疏松症的患病率随肌少症严重程度梯度升高: 无肌少症组为 47.6%, 疑似肌少症组显著上升, 确诊肌少症组高达 78.1%, 且骨质疏松症与确诊肌少症存在显著相关性($OR = 2.885$, 95% $CI: 1.155 \sim 7.204$) [9]。

特定人群的研究同样支持两者的双向关联。在 590 名芬兰绝经后女性中, 肌少症患者发生骨质疏松的风险是无肌少症者的 12.9 倍[10]; 232 名老年人中, 肌少症患者发展为骨质疏松的风险为非肌少症人群的 5 倍[11]。此外, 一项针对 3334 名老年人的研究采用 2019 年欧洲肌少症定义, 发现疑似和确诊肌少症患者的骨密度(BMD)及不同解剖部位骨结构指标均显著低于无肌少症人群, 进一步证实了两者的密切关联[12]。上述研究共同表明, 骨质疏松症与肌少症存在明确的双向风险关联, 为骨肌减少症的概念提供了坚实的流行病学依据。

2.2. 骨肌减少症的流行病学特征及危险因素

2009 年, Brinkly 等[13]首次提出“肌少-骨质疏松症”的概率, 定义为同时符合骨质疏松症诊断标准且伴肌量/功能下降的患者。作为老龄化社会的双重威胁, 其流行病学特征呈现显著的年龄、性别分层及地域差异, 国内与国外研究共同揭示了肌骨共病的严峻现状。

国内研究方面, 一项针对中国长沙 316 名 65 岁以上社区老年人的调查显示[14], 采用亚洲肌肉减少症工作组(AWGS)诊断标准时, 肌少骨质疏松症患病率男性为 10.4%, 女性为 15.1%, 性别差异显著($P = 0.024$)。该研究发现, 80 岁以上高龄($OR = 4.8$, 95% $CI: 3.05 \sim 10.76$)、合并 3 种以上慢性病($OR = 3.71$, 95% $CI: 1.61 \sim 10.43$)是患病核心危险因素, 且衰弱人群患病率(男性 26.3%、女性 38.5%)显著高于非衰弱人群(男性 1.6%、女性 1.9%), 提示肌少骨质疏松症与老年衰弱状态存在紧密关联。此外, 研究还证实肌少骨质疏松症患者发生衰弱/预衰弱的风险显著升高(男性 $OR = 4.16$, 女性 $OR = 4.67$), 为社区老年高危人群筛查提供了重要参考。

国外流行病学研究较早开展, 数据较为系统, 揭示了该共病在全球范围内的流行规律。早期, Di Monaco [15]等对意大利 313 名髌部骨折老年女性的研究发现, 肌少骨质疏松症患病率高达 45%, 肌肉减少症患者合并骨质疏松症的比值比为 1.80 (95% $CI: 1.07 \sim 3.02$), 明确了骨折高危人群中肌少骨质疏松症的高聚集性。随后, 多项研究提供了更深入的见解。如 Huo [16]等对澳大利亚有跌倒史的老年人研究显示, 肌少骨质疏松症患病率为 37%, 患者以女性为主(82.6%), 且常合并抑郁、营养不良及 mobility 障碍, 骨折发生风险较单纯骨质疏松或肌肉减少症患者显著升高($OR = 2.71$, 95% $CI: 1.7 \sim 4.4$)。一项纳入 17 项研究的系统综述与荟萃分析[17], 指出老年人群肌少骨质疏松症患病率为 5%~37%, 低能量骨折患者中肌肉减少症合并率达 46%, 且肌肉减少症患者骨折相对风险为 1.37 (95% $CI: 1.18 \sim 1.59$); 同期, Locquet [18]等对比比利时 288 名老年人的研究证实, 肌肉减少症患者骨质疏松症患病风险增加 4.18 倍(95% $CI: 1.92 \sim 9.12$), 且骨密度与肌肉质量、力量呈显著正相关。另一项对丹麦 529 名 65~93 岁居家老年人的研究显示[19], 采

用 EWGSOP2 标准时肌少骨质疏松症患病率为 1.5%，采用本地参考值时为 1.4%，肌肉减少症可使骨质疏松症患病风险增加 7.3 倍($P < 0.001$)；近期，有研究纳入 2353 名老年受试者(年龄 ≥ 60 岁) [20]，结果表明患病率男女分别为 33.8%和 33.9%，高体脂量、糖尿病及低体力活动是主要危险因素。

总体而言，肌少-骨质疏松症在老年人群中的患病率不容忽视，且随年龄增长而急剧上升，最终导致老年人骨折、失能及死亡风险[21]。

3. 病理生理机制

3.1. 机械因素

肌肉和骨功能密切相关，具有共同的机械和分子机制。肌肉和骨骼之间的机械相互作用由“机械调节器”理论加以阐释，该理论指出肌肉对骨骼施加机械力，如果这些机械力超过设定的阈值，骨转换的平衡就会偏离骨吸收，有利于骨形成[22]。据认为，这是因为肌肉质量的增加引起骨膜和胶原纤维的拉伸，从而刺激骨骼生长[23]。由于骨骼和肌肉质量与随衰老而观察到的身体机能下降有着内在联系，这证实了机械负荷在维持骨肌肉单位中的重要性。

3.2. 遗传因素

英国生物银行的数据显示，肌肉力量受遗传因素部分调控，且遗传因素对于峰值骨量的形成具有重要作用[24] [25]。从组织起源来看，肌肉和骨细胞均源自间充质干细胞，这也决定了二者会受到相似遗传因素的共同影响。

从遗传影响的程度来讲，骨质疏松症和肌少症各项危险因素的遗传度均处于 60%~70%的区间[23]。值得注意的是，肌少症与骨质疏松症存在部分高度重叠的差异基因表达谱，这类基因表达特征可实现对两种病症的同步调控[26]。在具体的基因层面，目前尚未发现单个基因或单核苷酸多态性，能够与骨量流失、肌肉力量下降及肌肉量减少存在联合关联；但全基因组关联研究已鉴定出多个与骨肌衰减相关的基因，其中生长分化因子 8 (GDF8)的特征研究最为充分[27]。此外，已有研究证实，维生素 D 受体基因多态性与肌少症和骨质疏松症均存在关联[28]。

3.3. 炎症因素

慢性炎症是免疫系统长期处于低水平慢性刺激下的表现，是终生暴露于抗原刺激与复杂的遗传、环境和年龄相关机制(包括线粒体功能障碍)相互作用的结果[29] [30]。同时，多项证据表明，慢性炎症通过多种信号通路影响肌肉蛋白质的分解和合成，会导致肌肉质量、力量和功能的丧失[31]。此外，有研究表明，低度慢性炎症可促使间充质干细胞向脂肪生成而非肌生成和成骨细胞生成分化，从而导致肌肉和骨骼质量下降[32]。并且，脂肪浸润是肌减少症和骨质疏松症的标志之一，骨髓脂肪组织含量高与骨质流失和骨质疏松症相关，肌内脂肪过多则与肌细胞功能障碍和肌肉质量下降有关[32]。

最后，除慢性低度炎症外，炎症性肠病(IBD)这类慢性炎症性疾病，还可能通过独立于全身性炎症之外的其他通路，影响肌肉与骨骼健康。例如，炎症性肠病常伴随钙、维生素 D、蛋白质等必需营养素的肠道吸收障碍，这会直接加速骨密度流失，同时间接损害肌肉力量与肌肉量[33]。

3.4. 内分泌因素

尽管慢性炎症是骨质疏松与肌少症关联的重要病理机制，但最近的研究表明旁分泌或内分泌串扰也发挥了作用。

介导这种串扰的重要激素包括生长激素、胰岛素样生长因子-1、性激素和维生素 D，随着年龄的增長，激素的减少会导致骨质疏松和肌少症的共同发生[34]。肌肉和骨骼还分泌某些因子，分别称为肌因子

和骨因子,有助于肌肉和骨骼之间的沟通[34]。一种被广泛研究的肌因子是肌生长抑制素,它是转化生长因子 β 超家族的成员,它抑制骨骼肌生长,但也对骨骼和肌腱产生影响[23]。

骨-肌肉串扰由几个重要的信号通路介导。例如,经典的 Wnt- β 连环蛋白信号通路控制成骨细胞活性,也参与肌肉再生[35];生长激素-胰岛素样生长因子-1 轴是骨骼和肌肉生长的关键调节因子,通过多种信号通路调节其作用。希望利用这些途径将促进未来新治疗药物的开发[34]。

4. 临床结果

肌肉减少症和骨质疏松症的存在与抑郁、营养不良、消化性溃疡、性关节炎和活动能力下降有关[16]。大量研究也证实,肌少症和骨质疏松症均会出现活动障碍的症状,老年人群的骨折可视为两者的共同后果。

其中澳大利亚和中国的研究表明,同时患有骨质疏松症和肌少症的人比单独患有骨质疏松症或肌少症的人跌倒和骨折的风险更高[14][16]。由此引发的骨折,尤其是髌部骨折,会导致严重的疾病负担。约有半数原本可以自主行走的患者,在髌部骨折后无法再独立活动[36]。此外,90岁以上人群中,有55%的患者在发生骨折后无法独立生活[36]。衰弱被定义为一种多维度综合征,是老年人因储备能力(体能、躯体功能、认知能力、健康状态)下降而产生的易损性状态[37]。许多老年人处于衰弱或衰弱前期状态,还患有骨质疏松症和肌少症;有一项研究显示,此类病症并存的比例在衰弱男性中为26.3%、衰弱女性中为38.5%;而在非衰弱人群中,男性的并存比例仅为1.6%,女性仅为1.9%[14]。一项针对韩国髌部骨折患者的研究显示,该群体的总体1年死亡率显著偏低;其中,合并骨质疏松症和肌少症的患者1年死亡率为15.1%,相比之下,单纯骨质疏松症患者的1年死亡率为5.1%,单纯肌少症患者则为10.3%[38]。

5. 综合治疗

5.1. 营养干预

营养干预是骨质疏松症与肌少症综合治疗的基础,其核心目标是通过补充关键营养素,协同改善骨密度与肌肉质量、力量,降低骨折及功能衰退风险。其中,膳食蛋白质、氨基酸及其衍生物、维生素D与钙是调控肌骨代谢的核心营养要素,各自发挥着不可替代的作用,且存在协同增效的调控机制。

膳食蛋白质作为肌骨组织合成的核心原料,对维持骨密度、骨骼强度及肌肉功能至关重要[39]。一项基于美国NHANES(2011~2018年)的横断面研究证实,蛋白质摄入与骨密度呈显著正相关[40]。补充蛋白质对肌少症患者同样获益,一项为期12周的饮食干预研究表明,中高蛋白质摄入组的老年女性肌少症患者,其握力、膝关节屈曲力量等肌肉功能指标,以及腿部、股部MRI肌肉横截面积均得到显著改善[41],体现了蛋白质对肌骨健康的双向保护作用。

值得注意的是,蛋白质的众多氨基酸中,亮氨酸的独特调控作用尤为突出。作为启动肌肉蛋白质合成的核心信号分子,亮氨酸可有效促进 ≥ 65 岁肌少症人群的骨骼肌合成,显著增加肌量[42]。同时,它也被证实可双向调节骨代谢——通过增强成骨细胞活性、抑制破骨细胞介导的骨吸收,直接影响骨密度[43][44]。针对难以通过膳食摄入足量蛋白质的老年肌少症合并骨质疏松症人群,专家共识进一步明确推荐口服亮氨酸(3.0~5.0 g/d),以协同改善肌量、肌力,减少骨量流失并提升骨密度[45]。

除了蛋白质及关键氨基酸外,维生素D与钙的协同作用同样是维持肌骨系统稳态不可或缺的核心环节。二者的调控机制具有明确的互补性:维生素D可促进肠道对钙的吸收[46],并通过调节钙-甲状旁腺激素轴维持骨代谢平衡,而钙则是骨矿化与肌肉收缩功能的必需物质。研究证据充分支持这一协同效应:联合补充钙剂与维生素D可显著提高骨质疏松症患者的骨密度[47];同时,活性维生素D类似物能显著改善老年人股四头肌力量,并将跌倒风险降低19%[48],这一结果凸显了二者在改善肌少症相关肌

肉功能衰退、降低跌倒风险中的重要价值，与蛋白质类营养素共同构成肌骨协同保护的核心网络。

5.2. 运动干预

运动干预作为低成本、高安全性的非药物策略，被广泛推荐用于维持肌肉骨骼健康[49]。其核心机制是通过高于日常活动阈值的适宜机械负荷，同步实现增加肌肉量、激活成骨细胞活性的双重效果[50][51]。该干预体系以阻力训练为核心，同时辅以有氧训练与平衡训练，共同形成多维度的干预支撑。

阻力训练作为核心模块，通过渐进式负荷刺激促进肌肉肥大[52]，同时肌肉收缩产生的机械应力可激活成骨细胞的 Wnt/ β -catenin 信号通路，提升骨密度[53]。一项针对骨质疏松症合并肌少症老年男性的随机对照试验证实，12 个月高强度抗阻训练后，运动组骨密度维持稳定、骨骼肌质量显著增加，而对照组两者均呈显著下降趋势[54]，充分印证了阻力训练的核心干预价值。

有氧训练与平衡训练作为重要补充模块，分别聚焦改善心肺功能与降低跌倒风险，与阻力训练共同构成完整干预体系。其中，负重有氧训练(如快走、爬楼梯)通过地面反作用力直接刺激骨重建，同时改善血液循环以保障骨骼肌氧供，维持肌少症人群的肌肉量及收缩功能；一项研究显示，12 周拳击训练(属负重有氧范畴)虽对肌肉量无显著影响，但能有效改善肌肉力量与功能，还可调节骨质疏松症相关标志物水平[55]。平衡训练(如太极、单腿站立)则通过优化神经肌肉协调能力降低跌倒风险，太极拳锻炼已被证实可安全改善老年肌少症患者下肢神经肌肉反应速度、增强动态姿势控制能力[56]。另有研究表明，平衡训练与抗阻训练联合应用时，对 80~99 岁高龄肌少症患者的日常生活活动能力及身体表现改善效果更优[57]。

运动与营养的协同干预是肌肉骨骼健康干预的重要优化方向。相较于单纯运动或单纯营养干预，运动联合蛋白质补充能更显著提升骨骼肌指数与握力水平[58]-[60]，且对绝经后女性的股骨颈、腰椎及髋关节骨密度有积极影响[61]，不过也有研究指出，目前尚不能得出“蛋白质 + 运动”联合干预比单一成分更能改善骨矿物质含量及骨密度的可靠结论，仍需更大样本量、更长随访时间的研究进一步阐明[62]。

5.3. 药物治疗

药物治疗骨质疏松症已经取得了很大进展，目前有多种直接针对骨代谢的治疗选择，以减缓骨质流失并促进骨形成[63]。其中，双膦酸盐类药物作为临床治疗绝经后骨质疏松症的一线方案，凭借明确的作用机制在临床中广泛应用。一项针对绝经后骨质疏松症女性的研究证实[64]，每年一次给药的唑来膦酸可通过特异性抑制破骨细胞增殖与活性，降低椎体(70%)及髋部(41%)骨折风险，同时提升骨密度。

相较于骨质疏松症，旨在对抗肌肉质量和力量逐渐丧失的肌少症的药物选择仍然较为有限。药物试验表明，肌抑素抑制剂通过阻断肌抑素对肌肉生长的抑制作用发挥疗效，在 II 期研究中可使瘦体重增加 3%~5% [65]；而选择性雄激素受体调节剂(SARM)是另一个有前途的途径，凭借组织选择性激活优势，既能规避传统雄激素的副作用，又能有效促进骨和肌肉合成[66] [67]；此外，RANKL 抑制剂地诺单抗(denosumab)，为骨质疏松合并肌少症的老年患者带来了新的治疗思路，这类药物不仅能发挥骨保护作用，还展现出对肌肉功能、平衡能力的协同改善价值[68]。

治疗逻辑上，骨质疏松症药物的成功源于对骨代谢的精准把控，肌少症药物研发则从“单纯增肌”转向“安全有效 + 功能协同”，SARM 的组织选择性、地诺单抗的多效性，契合老年患者“低副作用 + 多维度获益”需求。未来围绕“骨 - 肌联动”开发兼具针对性与协同效应的药物，将是填补肌少症治疗缺口、优化老年衰弱管理的关键。

6. 总结讨论

大量流行病学数据证实，骨质疏松症与肌少症在老年人群中存在高共患率，二者并非孤立发生，而是存在“共因 - 共果”的复杂关联。从本质来看，遗传因素、慢性炎症、激素变化等共同病理生理机制，

是驱动肌肉与骨骼组织同步恶化的核心动因。作为老年人群高发的综合征，二者协同作用显著提升了老年人虚弱、跌倒及骨折的发生风险，因此，二者的相互关联决定了临床干预中必须摒弃单一疾病治疗思维，采用综合治疗策略才是改善预后的关键。

然而，临床缺乏针对不同老年人群的个体化干预方案，且营养、运动、药物的协同效应未量化，相关共患病新兴药物的长期安全性与疗效也需更多验证。据此，未来研究应针对性推进：通过大样本长期研究明确二者关联机制，优化个体化干预方案并量化干预协同效果，验证“骨肌兼顾”药物的安全性与疗效，同时探索社区早期筛查与干预模式，减轻老龄化相关社会经济负担。

参考文献

- [1] 黄宏兴, 史晓林, 李盛华, 等. 肌少-骨质疏松症专家共识[J]. 中国骨质疏松杂志, 2022, 28(11): 1561-1570.
- [2] 中华医学会骨质疏松和骨矿盐疾病分会. 原发性骨质疏松症诊疗指南(2022) [J]. 中国全科医学, 2023, 26(14): 1671-1691.
- [3] Cruz-Jentoft, A.J., Bahat, G., Bauer, J., Boirie, Y., Bruyère, O., Cederholm, T., *et al.* (2019) Sarcopenia: Revised European Consensus on Definition and Diagnosis. *Age and Ageing*, **48**, 16-31. <https://doi.org/10.1093/ageing/afy169>
- [4] Tarantino, U., Greggi, C., Visconti, V.V., Cariati, I., Bonanni, R., Gasperini, B., *et al.* (2022) Sarcopenia and Bone Health: New Acquisitions for a Firm Liaison. *Therapeutic Advances in Musculoskeletal Disease*, **14**, 1-14. <https://doi.org/10.1177/1759720x221138354>
- [5] Clynes, M.A., Gregson, C.L., Bruyère, O., Cooper, C. and Dennison, E.M. (2021) Osteosarcopenia: Where Osteoporosis and Sarcopenia Collide. *Rheumatology*, **60**, 529-537. <https://doi.org/10.1093/rheumatology/keaa755>
- [6] Jin, S., Zheng, F., Liu, H., Liu, L. and Yu, J. (2025) The Correlation between Sarcopenia and Osteoporosis in the Elderly: A Systematic Review and Meta-Analysis. *Frontiers in Medicine*, **12**, Article 1603879. <https://doi.org/10.3389/fmed.2025.1603879>
- [7] Zhu, Y., Zeng, Q., Shi, Y., Qin, Y., Liu, S., Yang, Y., *et al.* (2024) Association between Sarcopenia and Osteoporosis: The Cross-Sectional Study from NHANES 1999-2020 and a Bi-Directions Mendelian Randomization Study. *Frontiers in Endocrinology*, **15**, Article ID: 1399936. <https://doi.org/10.3389/fendo.2024.1399936>
- [8] di Monaco, M., Castiglioni, C., Bardesono, F., Freiburger, M., Milano, E. and Massazza, G. (2022) Is Sarcopenia Associated with Osteoporosis? A Cross-Sectional Study of 262 Women with Hip Fracture. *European Journal of Physical and Rehabilitation Medicine*, **58**, 638-645. <https://doi.org/10.23736/s1973-9087.22.07215-x>
- [9] Kirk, B., Phu, S., Brennan-Olsen, S.L., Bani Hassan, E. and Duque, G. (2020) Associations between Osteoporosis, the Severity of Sarcopenia and Fragility Fractures in Community-Dwelling Older Adults. *European Geriatric Medicine*, **11**, 443-450. <https://doi.org/10.1007/s41999-020-00301-6>
- [10] Sjöblom, S., Suuronen, J., Rikkinen, T., Honkanen, R., Kröger, H. and Sirola, J. (2013) Relationship between Postmenopausal Osteoporosis and the Components of Clinical Sarcopenia. *Maturitas*, **75**, 175-180. <https://doi.org/10.1016/j.maturitas.2013.03.016>
- [11] Kirk, B., Zanker, J. and Duque, G. (2020) Osteosarcopenia: Epidemiology, Diagnosis, and Treatment—Facts and Numbers. *Journal of Cachexia, Sarcopenia and Muscle*, **11**, 609-618. <https://doi.org/10.1002/jcsm.12567>
- [12] Scott, D., Johansson, J., McMillan, L.B., Ebeling, P.R., Nordstrom, P. and Nordstrom, A. (2019) Associations of Sarcopenia and Its Components with Bone Structure and Incident Falls in Swedish Older Adults. *Calcified Tissue International*, **105**, 26-36. <https://doi.org/10.1007/s00223-019-00540-1>
- [13] Binkley, N., Krueger, D. and Buehring, B. (2013) What's in a Name Revisited: Should Osteoporosis and Sarcopenia Be Considered Components of "Dysmobility Syndrome"? *Osteoporosis International*, **24**, 2955-2959. <https://doi.org/10.1007/s00198-013-2427-1>
- [14] Wang, Y., Wang, Y., Zhan, J., Tang, Z., He, J., Tan, P., *et al.* (2015) Sarco-Osteoporosis: Prevalence and Association with Frailty in Chinese Community-Dwelling Older Adults. *International Journal of Endocrinology*, **2015**, Article ID: 482940. <https://doi.org/10.1155/2015/482940>
- [15] Di Monaco, M., Vallero, F., Di Monaco, R. and Tappero, R. (2011) Prevalence of Sarcopenia and Its Association with Osteoporosis in 313 Older Women Following a Hip Fracture. *Archives of Gerontology and Geriatrics*, **52**, 71-74. <https://doi.org/10.1016/j.archger.2010.02.002>
- [16] Huo, Y.R., Suriyaarachchi, P., Gomez, F., Curcio, C.L., Boersma, D., Muir, S.W., *et al.* (2015) Phenotype of Osteosarcopenia in Older Individuals with a History of Falling. *Journal of the American Medical Directors Association*, **16**, 290-295. <https://doi.org/10.1016/j.jamda.2014.10.018>

- [17] Nielsen, B.R., Abdulla, J., Andersen, H.E., Schwarz, P. and Suetta, C. (2018) Sarcopenia and Osteoporosis in Older People: A Systematic Review and Meta-Analysis. *European Geriatric Medicine*, **9**, 419-434. <https://doi.org/10.1007/s41999-018-0079-6>
- [18] Locquet, M., Beaudart, C., Bruyère, O., Kanis, J.A., Delandsheere, L. and Reginster, J. (2018) Bone Health Assessment in Older People with or without Muscle Health Impairment. *Osteoporosis International*, **29**, 1057-1067. <https://doi.org/10.1007/s00198-018-4384-1>
- [19] Nielsen, B.R., Andersen, H.E., Haddock, B., Hovind, P., Schwarz, P. and Suetta, C. (2020) Prevalence of Muscle Dysfunction Concomitant with Osteoporosis in a Home-Dwelling Danish Population Aged 65-93 Years—The Copenhagen Sarcopenia Study. *Experimental Gerontology*, **138**, Article 110974. <https://doi.org/10.1016/j.exger.2020.110974>
- [20] Fahimfar, N., Zahedi Tajrishi, F., Gharibzadeh, S., Shafiee, G., Tanha, K., Heshmat, R., *et al.* (2020) Prevalence of Osteosarcopenia and Its Association with Cardiovascular Risk Factors in Iranian Older People: Bushehr Elderly Health (BEH) Program. *Calcified Tissue International*, **106**, 364-370. <https://doi.org/10.1007/s00223-019-00646-6>
- [21] Laskou, F., Patel, H.P., Cooper, C. and Dennison, E. (2022) A Pas de Deux of Osteoporosis and Sarcopenia: Osteosarcopenia. *Climacteric*, **25**, 88-95. <https://doi.org/10.1080/13697137.2021.1951204>
- [22] Frost, H.M. (2003) Bone's Mechanostat: A 2003 Update. *The Anatomical Record Part A: Discoveries in Molecular, Cellular, and Evolutionary Biology*, **275**, 1081-1101. <https://doi.org/10.1002/ar.a.10119>
- [23] Kaji, H. (2014) Interaction between Muscle and Bone. *Journal of Bone Metabolism*, **21**, 29-40. <https://doi.org/10.11005/jbm.2014.21.1.29>
- [24] Sambrook, P.N., Kelly, P.J., Morrison, N.A. and Eisman, J.A. (1994) Genetics of Osteoporosis. *Rheumatology*, **33**, 1007-1011. <https://doi.org/10.1093/rheumatology/33.11.1007>
- [25] Tylavsky, F.A., Bortz, A.D., Hancock, R.L. and Anderson, J.J.B. (1989) Familial Resemblance of Radial Bone Mass between Premenopausal Mothers and Their College-Age Daughters. *Calcified Tissue International*, **45**, 265-272. <https://doi.org/10.1007/bf02556017>
- [26] 商海滨, 廉由之, 郭海玲, 等. 基于生物信息学探讨骨质疏松症与肌少症的关系[J]. 中国骨质疏松杂志, 2021, 27(10): 1458-1463.
- [27] Trajanoska, K., Rivadeneira, F., Kiel, D.P. and Karasik, D. (2019) Genetics of Bone and Muscle Interactions in Humans. *Current Osteoporosis Reports*, **17**, 86-95. <https://doi.org/10.1007/s11914-019-00505-1>
- [28] Rolland, Y., Czerwinski, S., van Kan, G.A., Morley, J.E., Cesari, M., Onder, G., *et al.* (2008) Sarcopenia: Its Assessment, Etiology, Pathogenesis, Consequences and Future Perspectives. *The Journal of nutrition, health and aging*, **12**, 433-450. <https://doi.org/10.1007/bf02982704>
- [29] Inglis, J.E. and Ilich, J.Z. (2015) The Microbiome and Osteosarcopenic Obesity in Older Individuals in Long-Term Care Facilities. *Current Osteoporosis Reports*, **13**, 358-362. <https://doi.org/10.1007/s11914-015-0287-7>
- [30] Baylis, D., Bartlett, D.B., Patel, H.P. and Roberts, H.C. (2013) Understanding How We Age: Insights into Inflammaging. *Longevity & Healthspan*, **2**, Article No. 8. <https://doi.org/10.1186/2046-2395-2-8>
- [31] Dalle, S., Rossmeislova, L. and Koppo, K. (2017) The Role of Inflammation in Age-Related Sarcopenia. *Frontiers in Physiology*, **8**, Article ID: 1045. <https://doi.org/10.3389/fphys.2017.01045>
- [32] Al Saedi, A., Hassan, E.B. and Duque, G. (2019) The Diagnostic Role of Fat in Osteosarcopenia. *Journal of Laboratory and Precision Medicine*, **4**, 1-8. <https://doi.org/10.21037/jlpm.2019.02.01>
- [33] Calvez, V., Becherucci, G., Covello, C., Piccirilli, G., Mignini, I., Esposto, G., *et al.* (2024) Navigating the Intersection: Sarcopenia and Sarcopenic Obesity in Inflammatory Bowel Disease. *Biomedicines*, **12**, Article 1218. <https://doi.org/10.3390/biomedicines12061218>
- [34] Girgis, C.M., Mokbel, N. and DiGirolamo, D.J. (2014) Therapies for Musculoskeletal Disease: Can We Treat Two Birds with One Stone? *Current Osteoporosis Reports*, **12**, 142-153. <https://doi.org/10.1007/s11914-014-0204-5>
- [35] Oliveira, A. and Vaz, C. (2015) The Role of Sarcopenia in the Risk of Osteoporotic Hip Fracture. *Clinical Rheumatology*, **34**, 1673-1680. <https://doi.org/10.1007/s10067-015-2943-9>
- [36] Chrischilles, E.A. (1991) A Model of Lifetime Osteoporosis Impact. *Archives of Internal Medicine*, **151**, 2026-2032. <https://doi.org/10.1001/archinte.1991.00400100100017>
- [37] Rockwood, K., Song, X., Macknight, C., *et al.* (2005) A Global Clinical Measure of Fitness and Frailty in Elderly People. *Canadian Medical Association Journal*, **173**, 489-495. <https://doi.org/10.1503/cmaj.050051>
- [38] Yoo, J., Kim, H., Ha, Y., Kwon, H. and Koo, K. (2018) Osteosarcopenia in Patients with Hip Fracture Is Related with High Mortality. *Journal of Korean Medical Science*, **33**, e27. <https://doi.org/10.3346/jkms.2018.33.e27>
- [39] Rizzoli, R. and Chevalley, T. (2024) Nutrition and Osteoporosis Prevention. *Current Osteoporosis Reports*, **22**, 515-522. <https://doi.org/10.1007/s11914-024-00892-0>

- [40] Chen, X., Fu, Y. and Zhu, Z. (2025) Association between Dietary Protein Intake and Bone Mineral Density Based on NHANES 2011-2018. *Scientific Reports*, **15**, Article 8638. <https://doi.org/10.1038/s41598-025-93642-w>
- [41] Ishaq, I., Noreen, S., Maduabuchi Aja, P. and Atoki, A.V. (2025) Role of Protein Intake in Maintaining Muscle Mass Composition among Elderly Females Suffering from Sarcopenia. *Frontiers in Nutrition*, **12**, Article ID: 1547325. <https://doi.org/10.3389/fnut.2025.1547325>
- [42] Gielen, E., Beckwée, D., Delaere, A., De Breucker, S., Vandewoude, M., Bautmans, I., *et al.* (2021) Nutritional Interventions to Improve Muscle Mass, Muscle Strength, and Physical Performance in Older People: An Umbrella Review of Systematic Reviews and Meta-Analyses. *Nutrition Reviews*, **79**, 121-147. <https://doi.org/10.1093/nutrit/nuaa011>
- [43] Kimball, S.R. and Jefferson, L.S. (2006) Signaling Pathways and Molecular Mechanisms through Which Branched-Chain Amino Acids Mediate Translational Control of Protein Synthesis. *The Journal of Nutrition*, **136**, 227S-231S. <https://doi.org/10.1093/jn/136.1.227s>
- [44] Bauer, J., Biolo, G., Cederholm, T., Cesari, M., Cruz-Jentoft, A.J., Morley, J.E., *et al.* (2013) Evidence-Based Recommendations for Optimal Dietary Protein Intake in Older People: A Position Paper from the PROT-AGE Study Group. *Journal of the American Medical Directors Association*, **14**, 542-559. <https://doi.org/10.1016/j.jamda.2013.05.021>
- [45] 中华医学会骨质疏松和骨矿盐疾病分会, 中国营养学会, 中国老年医学学会. 原发性骨质疏松症与肌少症的营养和运动管理专家共识(2025 年) [J]. 中华内分泌代谢杂志, 2025, 41(5): 355-364.
- [46] Nicolaysen, R. (1937) Studies Upon the Mode of Action of Vitamin D: The Influence of Vitamin D on the Absorption of Calcium and Phosphorus in the Rat. *Biochemical Journal*, **31**, 122-129. <https://doi.org/10.1042/bj0310122>
- [47] Liu, C., Kuang, X., Li, K., Guo, X., Deng, Q. and Li, D. (2020) Effects of Combined Calcium and Vitamin D Supplementation on Osteoporosis in Postmenopausal Women: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Food & Function*, **11**, 10817-10827. <https://doi.org/10.1039/d0fo00787k>
- [48] Xiong, A., Li, H., Lin, M., Xu, F., Xia, X., Dai, D., *et al.* (2024) Effects of Active Vitamin D Analogues on Muscle Strength and Falls in Elderly People: An Updated Meta-Analysis. *Frontiers in Endocrinology*, **15**, Article ID: 1327623. <https://doi.org/10.3389/fendo.2024.1327623>
- [49] Beck, B.R., Daly, R.M., Singh, M.A.F. and Taaffe, D.R. (2017) Exercise and Sports Science Australia (ESSA) Position Statement on Exercise Prescription for the Prevention and Management of Osteoporosis. *Journal of Science and Medicine in Sport*, **20**, 438-445. <https://doi.org/10.1016/j.jsams.2016.10.001>
- [50] Fleg, J.L. (2012) Aerobic Exercise in the Elderly: A Key to Successful Aging. *Discovery Medicine*, **13**, 223-228.
- [51] Palombaro, K.M., Black, J.D., Buchbinder, R. and Jette, D.U. (2013) Effectiveness of Exercise for Managing Osteoporosis in Women Postmenopause. *Physical Therapy*, **93**, 1021-1025. <https://doi.org/10.2522/ptj.20110476>
- [52] American College of Sports Medicine Position Stand (2009) Progression Models in Resistance Training for Healthy Adults. *Medicine & Science in Sports & Exercise*, **41**, 687-708.
- [53] Robinson, J.A., Chatterjee-Kishore, M., Yaworsky, P.J., Cullen, D.M., Zhao, W., Li, C., *et al.* (2006) Wnt/ β -Catenin Signaling Is a Normal Physiological Response to Mechanical Loading in Bone. *Journal of Biological Chemistry*, **281**, 31720-31728. [https://doi.org/10.1016/s0021-9258\(19\)84086-3](https://doi.org/10.1016/s0021-9258(19)84086-3)
- [54] Kemmler, W., Kohl, M., Fröhlich, M., Jakob, F., Engelke, K., von Stengel, S., *et al.* (2020) Effects of High-Intensity Resistance Training on Osteopenia and Sarcopenia Parameters in Older Men with Osteosarcopenia—One-Year Results of the Randomized Controlled Franconian Osteopenia and Sarcopenia Trial (Frost). *Journal of Bone and Mineral Research*, **35**, 1634-1644. <https://doi.org/10.1002/jbmr.4027>
- [55] Lin, Y., Chen, L., Chen, F., Wong, A.M., Hsu, C. and Chen, J. (2022) The Effectiveness of a Group Kickboxing Training Program on Sarcopenia and Osteoporosis Parameters in Community-Dwelling Adults Aged 50-85 Years. *Frontiers in Medicine*, **9**, Article ID: 815342. <https://doi.org/10.3389/fmed.2022.815342>
- [56] Huang, D., Ke, X., Jiang, C., Song, W., Feng, J., Zhou, H., *et al.* (2023) Effects of 12 Weeks of Tai Chi on Neuromuscular Responses and Postural Control in Elderly Patients with Sarcopenia: A Randomized Controlled Trial. *Frontiers in Neurology*, **14**, Article ID: 1167957. <https://doi.org/10.3389/fneur.2023.1167957>
- [57] Liang, Y., Wang, R., Jiang, J., Tan, L. and Yang, M. (2020) A Randomized Controlled Trial of Resistance and Balance Exercise for Sarcopenic Patients Aged 80-99 Years. *Scientific Reports*, **10**, Article No. 18756. <https://doi.org/10.1038/s41598-020-75872-2>
- [58] Yoshimura, Y., Matsumoto, A., Inoue, T., Okamura, M. and Kuzuya, M. (2025) Protein Supplementation Alone or Combined with Exercise for Sarcopenia and Physical Frailty: A Systematic Review and Meta-Analysis of Randomized Controlled Trials. *Archives of Gerontology and Geriatrics*, **131**, Article 105783. <https://doi.org/10.1016/j.archger.2025.105783>
- [59] Yang, Y., Pan, N., Luo, J., Liu, Y. and Ossowski, Z. (2025) Exercise and Nutrition for Sarcopenia: A Systematic Review and Meta-Analysis with Subgroup Analysis by Population Characteristics. *Nutrients*, **17**, Article 2342. <https://doi.org/10.3390/nu17142342>

-
- [60] Yan, R., Huang, W., Zhong, Y. and Du, X. (2025) Comparative Effectiveness of Exercise, Protein Supplementation, and Combined Interventions for Sarcopenia Management in Women: A Network Meta-analysis. *Nutrients*, **17**, Article 2392. <https://doi.org/10.3390/nu17152392>
- [61] Liu, J., Li, X., Zhang, W., Miao, T. and Wang, X. (2025) Effect of Combined Exercise and Nutrition on Bone Density in Postmenopausal Women—A Systematic Review and Meta-Analysis. *Nutrition & Metabolism*, **22**, Article No. 127. <https://doi.org/10.1186/s12986-025-01025-9>
- [62] Wolf, J.V.E., Schoene, D., Kohl, M., Kemmler, W. and Kiesswetter, E. (2025) Effects of Combined Protein and Exercise Interventions on Bone Health in Middle-Aged and Older Adults—A Systematic Literature Review and Meta-Analysis of Randomized Controlled Trials. *Osteoporosis International*, **36**, 609-625. <https://doi.org/10.1007/s00198-025-07393-5>
- [63] Eastell, R., Rosen, C.J., Black, D.M., Cheung, A.M., Murad, M.H. and Shoback, D. (2019) Pharmacological Management of Osteoporosis in Postmenopausal Women: An Endocrine Society Clinical Practice Guideline. *The Journal of Clinical Endocrinology & Metabolism*, **104**, 1595-1622. <https://doi.org/10.1210/je.2019-00221>
- [64] Black, D.M., Delmas, P.D., Eastell, R., Reid, I.R., Boonen, S., Cauley, J.A., *et al.* (2007) Once-Yearly Zoledronic Acid for Treatment of Postmenopausal Osteoporosis. *New England Journal of Medicine*, **356**, 1809-1822. <https://doi.org/10.1056/nejmoa067312>
- [65] Liu, X., Chen, X. and Cui, J. (2025) Therapeutic Advances in Sarcopenia Management: From Traditional Interventions to Personalized Medicine. *Clinical Nutrition*, **51**, 187-197. <https://doi.org/10.1016/j.clnu.2025.06.007>
- [66] Schmidt, A., Kimmel, D.B., Bai, C., Scafonas, A., Rutledge, S., Vogel, R.L., *et al.* (2010) Discovery of the Selective Androgen Receptor Modulator MK-0773 Using a Rational Development Strategy Based on Differential Transcriptional Requirements for Androgenic Anabolism versus Reproductive Physiology. *Journal of Biological Chemistry*, **285**, 17054-17064. <https://doi.org/10.1074/jbc.m109.099002>
- [67] Bhasin, S. and Jasuja, R. (2009) Selective Androgen Receptor Modulators as Function Promoting Therapies. *Current Opinion in Clinical Nutrition and Metabolic Care*, **12**, 232-240. <https://doi.org/10.1097/mco.0b013e32832a3d79>
- [68] Phu, S., Bani Hassan, E., Vogrin, S., Kirk, B. and Duque, G. (2019) Effect of Denosumab on Falls, Muscle Strength, and Function in Community-Dwelling Older Adults. *Journal of the American Geriatrics Society*, **67**, 2660-2661. <https://doi.org/10.1111/jgs.16165>