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在线全文

数字营养技术在成人体重管理中的应用*

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【摘要】 肥胖与超重是当下全球公共卫生难题，本文运用ARKSEY和O'MALLEY的范围综述框架，探讨了数字营养技术在体重管理中的应用。视觉识别技术从早期的食物图像识别发展至今，已初步成型，但鉴于食品种类繁多仍未成熟。可穿戴设备和非穿戴传感器的结合，提升了数据多样性和使用者的舒适度。数据整合分析工具如"数字虚拟孪生"，通过整合多维度数据，支持个性化干预。同时，各种新兴应用程序，也已展现出积极的临床效果。然而，现有研究存在样本量小、信息干扰多、证据质量不高等局限；数字营养产品的可及性不足，前期成本高昂。未来研究应扩展样本规模、人群多样性，并针对特殊目标人群的有效评估和调整进行探索，同时关注用户的隐私泄露风险。总体而言，数字营养技术为体重管理提供了新策略和手段，需持续研究、降本增效，以充分实现其在体重管理中的潜力，促进全民健康。

【关键词】 营养评估 体重管理 穿戴式设备 移动健康 超重 综述

Application of Digital Nutrition Technologies in Adult Weight Management

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[Abstract] Obesity and overweight remain major global public health challenges. In this paper, we examine current applications of digital nutrition technologies in weight management using the scoping review framework of Arksey and O'Malley. Visual recognition technologies have evolved from early-stage food image recognition into more advanced systems, although the vast diversity of food types continues to pose challenges for accuracy and generalizability. The combination of wearable devices and non-wearable sensors has increased the diversity of collected data and improved user comfort. Data integration and analysis tools, such as digital virtual twins, support personalized interventions by integrating multidimensional data. In addition, emerging applications have demonstrated encouraging clinical outcomes. However, existing studies have limitations, such as small sample sizes, high levels of information bias, and low evidence quality. Barriers, such as limited accessibility and high initial costs, further constrain the scalability of digital nutrition tools. Future studies should focus on expanding sample sizes, improving population diversity, and developing effective assessment methods and adjustments for specific target populations. Privacy and data security concerns must also be addressed to ensure safe implementation. Overall, digital nutrition technologies offer a promising approach to weight management, but continuous efforts in research and cost reduction are needed to fully realize their potential in weight management and to promote health for all.

[Key words] Nutrition assessment Weight management Wearable electronic devices Mobile health Overweight Review

当下，肥胖和超重日益成为全国乃至全世界范围内严重的公共卫生问题，因而体重管理（weight management）的概念应运而生。《中国居民营养与慢性病状况报告（2020年）》指出，中国18岁及以上成年人超重或肥胖比例达到34.3%，较2015年出现了显著增长[1]。根据《2025世界肥胖报告》预测：2030年体质量指数（BMI）≥25 kg/m^{2}的中国成年人数将达到515.04万[2]。近年我国慢性病患者人数不断增长，其导致的死亡占总死亡率的80%以上[1]。面对超重合并各种慢性病的严峻防控形势，党中央、国家卫生健康委相继规划了《健康中国行动（2019—2030年）》及"体重管理年"等活动，旨在倡导公众科学管理体重。自2015年精准医学的概念被提出[3]，营养学研究开始步入"互联网+"时代。政策推动与健康需求下，公众对体重管理需求迫切，数字营养技术凭借其便利、简洁等优势备受青睐，预防控制肥胖及相关疾病，具备公共卫生和经济价值。

鉴于此，本研究拟对现有的数字营养技术工具进行

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综述，并纳入现行的数字疗法，期望能为体重监测、减重研究探索新的方向。通过深入探索数字营养技术的应用潜力和优势，我们可以更好地实现体重管理的目标，为人们的健康生活提供有力的支持和保障。

1　数字营养技术赋能体重管理的优势

强化饮食管理(能量摄入)和身体活动(能量消耗)是通常使用的减肥手段。然而，世界卫生组织(WHO)与联合国粮食及农业组织(FAO)的报告却指出，当前有研究表明某些膳食结构或可降低某些疾病发生的风险，但尚不能完全明确单一营养素的具体作用[4]。过往基于营养素的膳食建议，往往侧重于食物中营养素的含量信息，对消费者的实际摄入量影响或许较为有限[5]。此外，人们通常对食品有一定的概念认知，而对营养层面的概念则较为模糊[4]。鉴于此，膳食干预指南的制定更多地依赖于整体膳食模式的管理。

传统营养学对于整体膳食的研究正面临诸多难题，如数据不准确、结论存在偏倚、研究对象依从性不佳等，问卷调查以及后续干预还普遍存在样本量较小以及失访现象等问题[6-8]。这对膳食健康行为的实现有阻碍，亟待更为有效的策略与技术来提供支撑。在这样的背景下，利用数字手段开展营养干预，实现体重管理，已然成为营养学领域的前沿课题与重大挑战。数字营养技术，作为一种新兴的营养学实践方式，将物联网、人工智能、大数据等数字化技术广泛应用于营养调查与评估、监测、干预、教育等众多领域，服务于精准营养的实践需求，有效解决了传统营养学长期以来存在的一系列问题[9]。它通过精准的数据收集和分析，为个体提供个性化的营养建议和干预方案，提高了营养干预的科学性和有效性。

2　数字营养技术赋能体重管理的纳入文献概况

本研究采用已被证实可靠性的ARKSEY和O'MALLEY的范围综述框架进行[10]。根据JBI范围综述手册推荐，在纳入文献中囊括知识用户，即临床医生、营养学家和数字工具使用者的访谈和意见[11]。在PubMed、Web of Science、Embase、中国知网、万方数据库5个数据库中进行了文献检索。另外通过临床试验注册库(ClinicalTrials.gov)、FDA的PMA与PAS数据库对临床疗法进行检索。

从相关数据库中初步检索到450篇文献，删除重复项后获得了370篇。根据纳排标准对题目和摘要进行筛选，确定了132篇进行全文筛选，从引文中纳入7篇文献。排除与数字营养技术工具无关(n= 30)，干预研究未显示与体重相关的结局(n= 24)，干预目标人群为婴幼儿、青少年(n= 13)，文献设计类型不符(n= 12)，灰色文献(n= 6)，无法获取全文(n= 5)，最终共有49篇文献纳入。未纳入的6篇灰色文献，包括1项针对居民的混合干预实验方案和5篇学位论文(均说明数字健康工具的积极作用)。

在49项研究中，有21项为RCT研究。研究在多个国家和地区进行，超过50%针对白种人进行。纳入的参与者年龄从18岁至80岁不等，其中2项针对老年人群。有11项研究仅纳入女性，81.8%与妊娠有关。样本量从20至3 951不等，干预时长从6周至36个月不等。36项研究将体重改变作为主要结局/主要研究方向，其他结局包括血压、血糖、血脂、心理状态、饮食摄入、健康行为、持续使用意愿等。27项研究中提及了合并高血糖、高血脂等慢性病状态的情况，其中包含了叠加“孕产妇”条件的情况。

采用混合评估法对纳入文献的方法学进行质量评估，对RCT研究使用Cochrane偏倚风险评估工具[12](图1)，证明偏倚风险较低。对非随机化的干预性研究使用ROBINS-I偏倚风险评估工具，中度风险和高风险均占比42.86%，没有严重偏倚风险的文献。其余文献均对数字营养技术可用性和使用方式进行叙述。

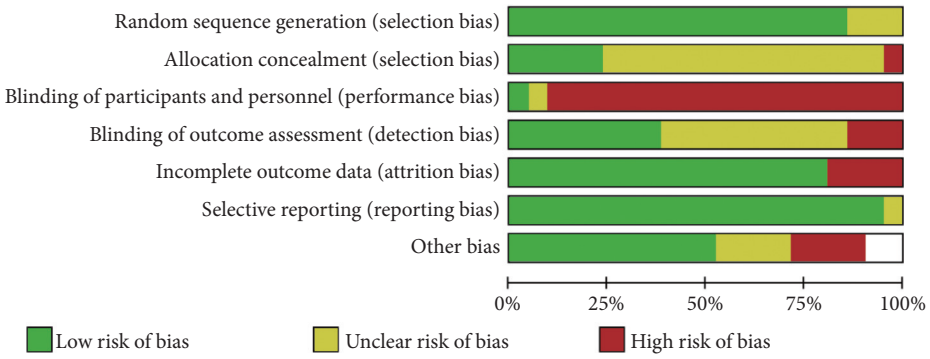

图 1　纳入RCT试验的偏倚风险估计

Fig 1　Risk assessment for biases of the RCTs included

3 数字营养技术赋能体重管理的理论依据

数字营养技术赋能体重管理有着坚实的理论依据。从能量平衡角度看,数字工具可精准监测记录个体能量摄入与消耗,如通过应用程序识别食物量、借助智能设备监测运动睡眠等,帮助用户了解自身能量收支情况,进而实现能量平衡调节;基于营养均衡理论,数字营养技术工具综合分析用户多维度数据,全面评估营养状况,并定制个性化饮食方案,优化营养摄入结构,满足身体对各类营养素的需求,为体重管理提供营养支持。

精准营养理论也是其理论依据之一。借助组学技术及大数据分析,对肥胖易感人群进行深度表型分析与精准分层,了解个体身体特征和代谢特点,并以此为靶点制定个体化干预策略,如针对肠道微生物失衡或特定基因变异个体,分别调整饮食结构或制定严格饮食运动计划,实现精准体重管理。同时,行为改变理论表明,数字营养技术工具为用户提供更加便捷的自我监测平台,增强其对自身行为的认知关注,通过设定目标、制定计划、发送提醒和鼓励消息等方式,对用户行为进行积极干预激励,提高用户依从性,促进行为改变。

此外,依从性提升理论强调数字营养技术工具应操作简便、使用便捷,如手机应用简洁易懂、智能设备数据自动同步,使用户轻松进行自我监测管理,提高依从性;还能根据个人偏好需求提供个性化体验服务,如定制饮食方案、推荐健康食谱、提供咨询服务等,提升用户满意度参与度,助力长期坚持体重管理。相关研究表明,目前存在的AI辅助饮食评估工具以及基于手机/Web的应用程序,大致可分为"基于图像"和"基于运动传感器"这两类,能够实现食物识别、分类、估计以及进食场合的捕捉等功能[13]。这些电子设备相较24 h回忆、FFQ等传统方法更加精确,偏倚更少[14],将有助于提高营养护理的质量。

在采集设备不断得到优化的当下,营养学领域所需的数据信息也变得愈发繁琐复杂。这些数据涵盖了各种营养筛查信息、膳食摄入量、临床参数等诸多方面,且变量种类繁多,彼此之间存在着千丝万缕的联系。这使得传统的研究方法在处理这些数据时,需要耗费大量的时间和人力[15]。而机器学习方法能够通过降低维度、识别模式和对相似数据点进行分组来管理这种复杂性。这些工具可以在研究和临床实践中实现准确预测及个性化设计[16],通过建模不仅可以了解特定食物对个体代谢参数的影响,还可以明确导向某种情况的主要因素[17]。因此,充分发挥机器学习与人工智能的优势,有助于实现精准营养和个性化体重管理。

4 用于体重管理的数字营养技术研究现状

4.1 智能膳食营养评估工具

当前技术趋势聚焦多模态数据融合,通过整合膳食识别与运动监测数据构建"摄入-消耗"动态模型[18],基于能量平衡理论提升体重管理持续性[19],可以辅助饮食干预、为归因分析提供量化依据[20]。

膳食识别技术始于二十世纪八十年代,HANKIN和WILKENS率先采用标准化食物图像辅助纸质膳食评估[21]。早期的食物图像识别依赖可穿戴设备进行数据采集[22],存在依从性限制与图像质量缺陷。传统摄影法能改善精度(中位数偏差= 0.15 ~ 1.64 g),但需依赖人工解析[23]。应用程序Nutrinote Gama可实现与称重法差异无统计学意义的人工评估[24]。远程实物摄影法(RFPM)实现自动化,通过餐盘影像与标准图谱比对,重量识别误差率降至0.32% ~ 1.58%[25]。深度学习方法的应用显著提升识别精度,如ZHANG等[26]开发的非穿戴式系统(nWFRS)在1 455张图片中平均准确率89.60%,主食类别可达到95.83%。MA等[27]建立了首个中餐图像数据库ChinaFood-100,可用于训练深度学习模型。从传统摄影到深度学习方法,准确度和自动化不断提升。

纳入文献中的数字营养技术总结于附表1,纳入RCT实验中不同人群的减重效果对比见附表2(见网络资源附件)[24-72]。当下可穿戴式设备已不限于辅助膳食识别,通过收集包括脉搏心率、睡眠状态、行走步数等多种数据参与代谢监测。物理监测手段中,SAZONOV等[28]基于从喉部麦克风获取的音频信号来预测食物摄入量,可识别几种不同的食物的吞咽动作。SEN等[29]使用智能手表的惯性传感器来捕捉进食活动和进食方式,准确率达到85%以上。为了排除环境干扰和身体活动干扰,FAROOQ等[31]采用压电应变传感器和加速度计来区分不同类型的活动并持续监测食物摄入。生理监测手段则针对代谢物,例如监测间质液的连续酮监测器也可针对超重或肥胖人群的生酮饮食[73]。SEMPIONATTO等[33]、YANG等[34]的研究都是通过汗液传感器来跟踪代谢产物,从而构筑代谢-营养管理。此外,被嵌入传感器的"智能餐具""智能桌布"能重建餐具运动轨迹,据此确定膳食类型[30]。

4.2 多模态营养与健康数据分析与呈现工具

在体重管理的需求合并慢性病等复杂背景的场景中,数字建模与AI技术为研究者和医务工作者提供了风险预测手段与个性化减重治疗依据,于减重方面的有效性已得到证实。

将遗传信息与纵向代谢组学、免疫、行为和肠道微生物参数以及各种生物临床变量相结合，定义个体自己的数字副本，就是“数字虚拟孪生”[74]。营养学研究已证明受遗传调控的饮食行为会影响个体的体重，表观遗传调控对饮食偏好的影响显著[75]。在代谢性疾病干预场景中，数字孪生用多种建模方法实现了多模态数据协同分析，如代谢动力学模块整合米氏方程与流量平衡分析。SHAMANNA等[43, 57-58]利用数字孪生对2型糖尿病人群进行了系列研究，观察到糖尿病指标、体重指标的改善伴随活动增多，并基于个性化的代谢状态对患者的食谱和药物进行了调整。应用于多囊卵巢综合征患者，也观察到有效的症状改善和体重减轻[59]。

3种最常见的AI技术——机器学习、深度学习、自然语言识别，应用于营养学调查，能发挥统计数据、处理饮食模式、风险预测、识别数据特征和整合各来源的信息等等作用。面对营养代谢疾病，决策树、神经网络、长短期记忆模型能做出优秀的诊断和预测，例如预测肥胖人群接受减肥手术的结果比较风险收益[76]。

4.3　动态营养干预与指导工具

以减重人群为直接用户的一类数字工具通常在干预期间展现出有效性。短信、电话访谈、视频会议是常见的远程指导手段，然而这类干预单独存在时往往依赖人工。应用MMM允许用户设定减肥目标，在电子食物日记里记录摄入和活动，根据用户卡路里目标的进度触发每周短信，提高用户的自我效能感[37]。在应用程序或其他干预的基础上，混合远程干预手段也被证明有效[77]。

随着智能手机的普及和应用软件的更新换代，自发式饮食追踪也从纸质转变为数字日志，为膳食改变提供更多正反馈。应用程序Vegethon以“挑战”“排行榜”形式，显著增加了有减肥意图的超重人群的蔬菜消费量，尤其是十字花科蔬菜和橘黄色蔬菜[35, 78]。为了维持依从性和参与度，自动数据追踪设备[56]、摄影食物日记也有着不小的市场；这些日志与其他形式的信息（如文字）、技术（如AI）结合提高保留率和解释性[73]。

基于网络和智能手机的一体化工具集数据收集、分析于一身，对比过往决策生成食谱，最终改善包括营养知识和体重在内的临床结局。AI4Food数据库集食物图像、传感器、问卷和生物样本于一体，收集精准营养减肥干预的个体信息[36]；一项含个性化饮食与干预的营养应用改善了超重老年人的体重、活力、情绪健康等多项指标[60]。我国多地则响应国家号召兴起智慧食堂模式，营养报告、慢病管理与配餐绑定，为个体生成带量食谱[79]。

4.4　数字营养技术衍生的临床产品国内外市场现状

MyFitnessPal的Calorie Counte是经典的国际产品，与多平台数据整合，能计算能量和营养素含量[32]。Fitbit的主要产品是可追踪运动的手表、手环，手机应用可以与设备串联记录体重、消耗等各项数据[42, 49]。通过movisensXS开发和运行的软件APPetite，可以连续捕获膳食摄入、身体活动、相关因素（如压力）信号，适用于精神病患者饮食监测，创造性结合了身体活动和摄入[20]。我国市场认知度较高的软件Keep定位是运动健身平台，但载入了图像识别技术并提供了饮食运动的联动评估，通过社交裂变策略实现月活增长。薄荷健康是我国最早的健康管理平台之一，目前已有1.6亿用户，形成“评估-干预-产品-服务”闭环生态。

我国与国外的营养平台相比，用户基数大，用户画像模糊，面向特殊人群（如精神病患者）的研究相对较少[20]。依托多端设备联动，欧美国家收集同一个体多种数据，而我国此种数据库的建立刚刚起步。目前我国用户大多依然是中青年，然而过去10年中的许多数字产品定价高昂、量级太重，导致昙花一现。如何适配我国国情和市场，是研究者和经销商需要面对的问题。

综上所述，数字营养技术在体重管理中展现出的干预效果显著。如前文大规模队列研究证实，围绕网络应用程序的联合生活方式干预（CLI-WL）可使超重人群平均减重3.7 kg，肥胖人群减重幅度达5.4 kg[61]。国内外多种设备与应用已有研究证据支撑，展现出良好的前景。部分面对特殊人群（老年人、孕产妇、慢性病患者）的研究也证明基于多模态数据整合的个性化方案可有效促进体重下降。但值得注意的是——干预效果与用户依从性密切相关，高频使用AI膳食记录工具（如Fitbit应用）的参与者减重幅度显著高于低频用户[44, 56]。

5　总结与展望

5.1　数字营养技术在成人体重管理中的优势

本综述通过提供营养学领域最新应用于体重管理的技术概览，证明基于精准营养、个性化饮食的数字营养技术对体重控制有积极作用：其具有高度的实用性和灵活性，以系统化膳食指南的方式，密切监测使用者的食物组成、体重及其他健康指标，从而生成解释性良好的膳食建议；在我国超重人群持续增长的背景下，数字营养技术有助于提高自我监测、自我干预的科学性，减轻临床诊疗压力，并促进医疗信息的公平性与可及性。例如，AI4Food数据库通过整合多模态数据，为资源匮乏地区提供可负担的膳食指导，初步验证了技术普惠的潜力[36]。

5.2 数字营养技术在成人体重管理中面临的问题和挑战

尽管前景广阔,数字营养技术的应用仍面临多重制约:其一,现有研究普遍存在样本量小、质量参差的问题,且针对非白人群体研究不足,限制结论外推性;其二,根据2025年的一项研究,个性化营养市场的主要挑战之一是前期成本高昂,因而对低收入人群的影响还需进一步探究[80];其三,复杂场景适应性不足,妊娠期动态需求、慢性病共病等造成的偏差尚未完全厘清;其四,健康数据聚合可能引发隐私泄露风险[81]。突破这些瓶颈仍需政策支持(如医保纳入)、技术开源(如共享多民族饮食数据库)及伦理框架完善,以实现技术的规模化与可持续发展。

5.3 数字营养技术在成人体重管理中的未来展望

为了推动数字营养技术的多样化、精准化发展,未来研究首先要拓展混合干预模式,开发适配复杂场景的功能性工具。其次,扩大研究覆盖人群,聚焦亚裔、非裔、拉美裔等研究不足的人种,探索文化、饮食偏好与技术适配性的关联。另外,针对合并慢性病的特殊人群,添加动态摄入消耗评估模型,实现个性化干预方案的实时优化。例如,基于数字孪生技术整合遗传、运动与饮食数据,动态调整患者的营养摄入阈值。未来也需通过"医+X"合作推动技术从个体化向群体健康管理延伸,最终服务于"健康中国2030"战略目标。

* * *

作者贡献声明 熊子涵负责论文构思、数据审编、正式分析、调查研究、研究方法、可视化和初稿写作,樊宁负责论文构思、正式分析、调查研究、研究方法、验证和审读与编辑写作,赵月负责论文构思、数据审编、调查研究、研究方法和审读与编辑写作,闫媛媛负责论文构思、经费获取、研究方法、研究项目管理和审读与编辑写作,王慧负责经费获取、研究项目管理、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 XIONG Zihan is responsible for conceptualization, data curation, formal analysis, investigation, methodology, visualization, and writing--original draft. FAN Ning is responsible for conceptualization, formal analysis, investigation, methodology, validation, and writing--review and editing. ZHAO Yue is responsible for conceptualization, data curation, investigation, methodology, and writing--review and editing. YAN Yuanyua is responsible for conceptualization, funding acquisition, methodology, project administration, and writing--review and editing. WANG Hui is responsible for funding acquisition, project administration, 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 take responsibility 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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