



Views & Comments

变革生命科学研究范式,构建全息数字人体模型

丛斌^{a,b,g,*}, 刘欣安^c, 张世明^d, 倪志宇^e, 王立平^{c,f}^a Hebei Key Laboratory of Forensic Medicine, College of Forensic Medicine, Hebei Medical University, Shijiazhuang 050017, China^b College of Integrated Traditional Chinese and Western Medicine, Hebei Medical University, Shijiazhuang 050017, China^c CAS Key Laboratory of Brain Connectome and Manipulation, Shenzhen-Hong Kong Institute of Brain Science, Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences, Shenzhen 518055, China^d Bigmath (Shenzhen) Technology Co., Ltd., Data Intelligence Research Institute, Shenzhen 518063, China^e School of Basic Medical Sciences, Hebei University, Baoding 071000, China^f Guangdong Provincial Key Laboratory of Brain Connectome and Behavior, the Brain Cognition and Brain Disease Institute, Shenzhen Institute of Advanced Technology, Chinese Academy of Sciences, Shenzhen 518055, China^g Research Unit of Digestive Tract Microecosystem Pharmacology and Toxicology, Chinese Academy of Medical Sciences, Shijiazhuang 050017, China

1. 构建全息数字人体模型的必要性

生物机体以自我更新、自我复制、自我调节的方式维系生命体活动所表征的高智能、自组织、自稳态、新陈代谢、自我修复、自我繁衍的过程,也是多系统协调运动的过程[1]。生命领域的研究不能仅局限于用先进的观测手段揭示亚细胞水平或分子水平的微观结构。基于这些方法发现的静态结构无法表征生命的微观动态过程[2]。在生命科学领域,美国相继启动了人类基因组计划(Human Genome Project, HGP)[3]、人类蛋白质组计划(Human Proteome Project, HPP)[4]、人类微生物组计划(Human Microbiome Project, HMP)[5]和人类细胞图谱(Human Cell Atlas)计划[6]。这些计划的实施使美国占据了科学技术研究领域的全球领先地位。但是这些计划并未系统揭示人类生命活动从宏观到微观层面的基本演化规律[2,7],也未系统揭示以调节生物分子网络为特征的具体生物功能,如蛋白质及其时相性动态变化过程。根据中心法则,从DNA到蛋白质,人类认识生命的探索已然深入到了分

子层面[8]。然而,当前医学科学面临的困境和需要突破的难题是,如何通过探索分子间的关联关系及其所表征功能的时相性变化规律等,从整体上系统揭示生命的本质和演化规律。因此,生命科学研究一直致力于寻求对人类生命本质规律认知的实质性突破[9],进而加深我们对于疾病发生发展的确切病理机制、治疗疾病有效的干预措施及康复措施的认知[10–12]。系统生物学概念成为主流,即从系统的层面上研究生命活动[13]。随着系统生物学的发展,医学研究整体水平逐渐转向了注重整体性和复杂性的系统生物医学[14]。例如,在肿瘤[15–16]、心血管疾病[17–18]、代谢性疾病[19–20]、呼吸系统疾病[21]和自身免疫性疾病[22–23]等慢性疾病的认知和治疗方面,整体论思想的应用逐渐广泛,而不再是“一病一药”的治疗策略。但我们仍缺乏从宏观层面到微观水平的系统研究,这将有利于更好揭示人类生命、健康和疾病的需求[24–27]。

以基因组学[28]、蛋白质组学[29]、代谢组学[30]和转录组学[31]等系统生物学为代表的生命科学研究领域的技术进步,为现代生物医学在生物大分子、亚细胞结构、细

* Corresponding author.

E-mail address: hbydcongbin@126.com (B. Cong).

胞、细胞间连接、组织、器官、系统和整体层面解析各生物分子、组分、细胞之间的网络关联关系提供了可能性[32–34]。创新的算法使我们能够获取生命活动过程中器官、组织和细胞水平动态变化的海量生物数据信息[35]。通过信息科学技术模拟、复现或再现相关生命活动的网络化过程，如“数字孪生”，解码生命活动的本质[36]。生命科学与信息科学技术的深度融合，是研究范式的转变，其从根本上促进了生命科学研究的进步[37]。因此，有必要建立新的科学范式[38]，来研究生命科学领域的三大基本科学问题：①解析人体微观结构；②揭示人体微观结构间的关联关系；③探索人体微观结构及其功能的时相性变化规律。对人体全息生命系统网络解析的科学研究，使我们能够从细胞水平揭示生命活动全景，探索重要器官的生命活动网络机制[39–41]，精细解析大脑调控机体稳态平衡机制，例如，中枢神经系统[42]与外周多脏器[43–50]相互调控的神经网络，以及构建全息数字人体模型。

全息数字人体模型是利用数字孪生、计算机模拟等技术重建人体微观、中观和宏观网络化动态生命信息数据，实时呈现人类生命系统活动的生理和病理过程的数学模型。它包括不同聚集状态细胞内生物分子的动态网络、特定器官的细胞间动态网络，以及器官之间的动态网络，如大脑与外周器官之间的网络或外周器官之间的网络。全息数字人体模型以物联网（Internet of Things, IoT）的运行模式进行工作，具有自组织、自动化和自耦联的特点[51]。其主要应用目标有以下几点：①揭示人体组织和器官的网络结构；②根据全息数字人体计算或微观结构和功能改变表征的生理生化指标、影像学、电生理学、核磁变化数据，评估个体健康、亚健康状态或疾病程度；③针对不同患者个体特征，为其制定精准医疗策略；④在多靶向系统性干预和调节的基础上创新治疗方法；⑤揭示中医诊治疾病的原理；⑥为未来的考古学和人类学研究建立永久性精准数字人体模型；⑦促进仿生学发展；⑧促进信息科学及其他自然科学技术全面进步；⑨支持中国人才培养和世界科技高地建设。

人体全息生命系统的刻画是对已发表的相关科学研究结果数据进行分类、整合并数字化，利用先进的科学技术手段对人类复杂生命活动过程进行解码，为推动生命科学研究进入“数据密集型科学发现”时代提供新范式，从宏观到微观全面认知人的生命本质[41,52]，解析人体全息生命系统，从多系统间相互调控机制着手解密人类生命健康密码[53]。以新的科学范式解析人体能量信息网络传递机制，不仅有助于我们洞察人体变化、探究致病机制、精准疾病诊疗，还可以有效开展疾病预防，助力健康中国建设

[54–55]。

2. 解析人体信息能量网络机制的工作进展

由丛斌院士牵头组织的第696次香山科学会议于2021年4月10–11日在北京召开，会议以“揭示生命领域三大科学问题，解析人体能量信息网络机制”为主题。来自医学、生物学、生命科学、中医、数学、物理学、人工智能和信息技术等40余名多学科跨领域专家学者参加了此次会议。会议达成共识，共同倡议发起以“数字生命与全息人体”为主旨的重大科学研究战略计划。该计划的主要内容包括：①从人体微观层面全面解密生命活动的本质；②建立人体重要器官的生命活动网络模型；③解析中枢与外周多脏器相互调控网络机制；④构建全息数字人体模型；⑤建立青年科学家领军人才培养体系。

会议期间，与会专家为研究项目的实施制定了一系列计划。为了该项目的运行，有必要建立一个“1+N”模式的集中式数据中心用于构建数字生命与全息人体，其中，N代表不同的机体系统，如不同器官间的数字连接组。目前已取得了一些重要的研究进展，包括灵长类动物全脑图谱绘制[56]，特定类型神经元的单细胞分辨率全脑投射[57]，以及利用全身成像建立系统的神经核代谢连接框架[50,58–60]。此外，为满足“数字生命与全息人体”计划的算力基础需求，贝格迈思（深圳）科技有限公司开发了异构智能内存计算一体机“MEMORY MACHINE”。该公司正致力于建立存算一体的数据平台（称为“BigInsights”），从生命活动演变中获取海量数据和新知识，将其转化为数学模型，以实现数字生命与全息人体的全面系统刻画。

“数字生命与全息人体”计划将搭建全球协作的平台，汇聚国内外力量，促进生命科学、医学和信息科学技术的发展；建立国际化、前瞻性技术与科学研究中心，吸引杰出人才。这项计划工程量巨大，需全球科学家共同协作，建立全球统一的国际合作框架和标准。

3. 全息数字人体模型的发展前景

构建全息数字人体模型是全球性的重大战略计划。实施该项重大研究计划，能够促进医学、生命科学、信息科学、化学、物理学和数学的深度融合，实现共创新和共发展。该模型在中医本体论和整体论的方法论指导下提出并建立。例如，根据人体全息理论，身体的某一部位可能承

载着身体的整体信息。在中医诊断方法中，面部和舌与内脏器官之间有着从属关系，两者都能在一定程度上反映身体的整体状况，这是全息理论应用在中医诊治中的体现之一。此外，全息数字人体模型是研究身体功能的重要工具，也是研究中医本体论、整体论和系统论的重要工具。毋庸置疑，中医的本体论和整体论仍然是现代系统医学的组成部分，并将继续在当代医学实践，尤其是补充和替代医学领域中发挥重要的作用[61–62]。同时，利用全息数字人体模型的优势，能够帮助解读中医学中的脏腑和经络理论[63–66]。

该重大研究项目借鉴了中医本体论和整体观的认识论和方法论。通过解析生命物质和非生命物质演变的四维空间运行规律，建立信息科学、脑科学、物理学、现代医学、生命科学和中医等领域的交叉融合平台，实现对数字生命、全息人体、生命活动本质的全面系统刻画[67–68]。这一全球性重大研究计划将促进医学、生命科学、信息科学、化学、物理学和数学的深度融合，进而促进相关学科领域科学技术的全面进步[69]，同时将科研成果转化为生产力[70–71]。该研究计划聚焦国际研究前沿，建立了集原始创新、技术研发、人才培养、技术应用和产业于一体的新模式，共同实现“五位一体”综合发展及新型产业形态建立。

“数字生命与全息人体”重大研究计划旨在解析人体全息生命系统，从多系统间相互调控机制着手解密人类生命健康密码，该过程依赖于所有科学进步的成果和工程实践，是现有科技进步成果的集大成[72–75]。随着人体全息生命系统的逐层解密，会带来诸多新的挑战 and 新的机遇，将进一步促进科学技术的全面发展。

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