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编者按：2024浦江创新论坛——国际人类表型组论坛以“表型组与精准医学”为主题，围绕人类表型组国际大科学计划实施进展、人类表型组与精准医学研究现状与未来动向等展开深入研讨。本期专报对国际人类表型组论坛的嘉宾观点进行梳理，供参考。

Editor’s note: With the theme of “Phenome and Precision Medicine”, the International Human Phenome Forum under the 2024 Pujiang Innovation Forum conducted in-depth discussions on the implementation progress of the Major International Science Program on the Human Phenome, and the current status and future trends of human phenome research and precision medicine. This special report summarizes the viewpoints of the guests at the International Human Phenome Forum for your reference.

2024 浦江创新论坛专报之二

Special Report 2 of the 2024 Pujiang Innovation Forum

深入理解生命密码　驱动精准医学创新发展

Gaining insights into the life code to drive the innovation and development of precision medicine

人类表型组是指人体从胚胎发育到成长、衰老、死亡过程中所有生物学性状的集合。表型组的精准测量对于理解生命、推动医学进步具有重大意义，将引领生物医药产业的巨大变革。**与会嘉宾一致认为，当前人类表型组研究进入创新突破期，需重点聚焦大规模人群队列的跨尺度、全周期人体系统精密测量，以国际大科学计划推进全球大协作，探寻“基因-环境-表型”之间的关联关系与调控机制，绘制未来生命科学“导航图”。**

The human phenome refers to the collection of all biological traits in the human body from embryonic development to growth, aging and death. Precise phenome measurement is significant for understanding life and promoting medical progress, and will bring about a huge transformation in the biopharmaceutical industry. **The guests present agreed unanimously that currently, human phenome research has entered an innovation breakthrough stage, and should focus on cross-scale, full-cycle precise measurement of the human body system in large-scale population cohorts,**

promote global collaboration through major international science programs, explore correlations among genes, the environment and phenotypes, and associated regulatory mechanisms, and draw a future "navigational chart" for life sciences.

一、表型组研究的战略意义

1. Strategic significance of phenome research

一是表型组研究为破解人类生命密码提供"新思路"。表型组作为基因组之后生命健康领域的下一个战略制高点，全面覆盖了从胚胎发育到衰老死亡的生物学性状。**复旦大学人类表型组研究院执行院长田梅**强调，揭示宏观表型的微观机制是生物医学的核心问题。**中国科学院分子细胞科学卓越创新中心研究员刘默芳**指出，表型组研究有助于系统了解生物体内细胞发生、发育过程中的基因调控机制，揭示生物的基本生物学现象。

First, phenome research provides "new ideas" for deciphering the human life code. As the next strategic commanding point in the life and health field following genomics, the phenome covers biological traits from embryonic development to aging and death comprehensively. **Tian Mei, President of the Human Phenome Institute, Fudan University**, emphasized that revealing microscopic mechanisms of macroscopic phenotypes is a core issue in biomedical research. **Liu Mofang, research fellow at**

the Center for Excellence in Molecular Cell Science, Chinese Academy of Sciences, pointed out that phenome research helps to understand gene regulation mechanisms in the process of cell genesis and development in organisms, and reveals basic biological phenomena of organisms systematically.

二是表型组研究和深度表型测量为精准医学提供"新方案"。美国四院院士、中国科学院外籍院士、美国系统生物学研究所联合创始人莱诺·胡德指出，现代科技和精确测量手段为个性化健康管理提供了科学方法，人类表型组研究能够在疾病发展的早期阶段捕捉关键生物信号，从而实现精准预防治疗，推动以"疾病为中心"向"健康为中心"转变。**山东大学临床研究中心执行主任吕明**认为，人类表型组研究是精准医学的关键，实现"千人一药"到"一人一方"。**田梅**指出，之前研究显示，30%的表型是有年龄和性别的差异，未来人类表型组研究将尝试围绕正常中国人在不同年龄段的各种表型正常值进行测量，有针对性制定符合中国人群特征的 BMI、血糖、血压等健康标准。**刘默芳**提出，人类表型组研究能有效应用于个体生育力的下降预警。

Second, phenome research and in-depth phenotype measurement provide a "new solution" for precision medicine. Leroy Hood, academician of the National Academy of Sciences, National Academy of Engineering, National Academy of Medicine, and Academy of Arts and Sciences of the U.S., foreign academician of the Chinese Academy of Sciences, and

co-founder of the Institute of Systems Biology, pointed out that modern technology and means of precise measurement provide scientific methods for individualized health management, and human phenome research can capture key biological signals at the early stage of pathogenesis, thereby realizing precise prevention and treatment, and promoting the shift from the "disease centered" approach to a "health centered" one. **Lu Ming, Executive Director of the Clinical Research Center, Shandong University**, thought that human phenome research is the key to precision medicine as it can realize the shift from "one drug for multiple people" to "person-specific prescriptions". **Tian Mei** pointed out that prior research has shown that 30 percent of phenotypes have age and gender differences, and future human phenome research will attempt to measure normal values of various phenotypes of normal Chinese people of different age groups, and formulate targeted health standards for BMI, blood sugar, blood pressure, etc. that are suited to the features of Chinese people. **Liu Mofang** proposed that human phenome research can be applied to the early warning of individual fertility decline effectively.

三是表型组研究为生物医药产业升级提供"新动能"。通过深入挖掘表型数据，能够帮助科学家更快速、更准确发现药物新靶点、生物新标志物和机理新机制，加速技术创新和新药研发。**田梅**认为，人类表型组研究可作为创新药物研发的策源地，尤其是

在基于中国人群的药物靶点识别、生物标志物发掘以及机制探索上具有重大意义。**刘默芳**提出，人类表型组研究为男性不育药物的研发提供了全新思路。

Third, phenome research provides a "new driving force" for the upgrading of the biopharmaceutical industry. Delving into phenotype data can help scientists discover new drug targets, biomarkers, and mechanisms more quickly and accurately, and accelerate scientific and technological innovation, and new drug development. **Tian Mei** thought that human phenome research can serve as the cradle of innovative drug R&D, especially in drug target recognition, biomarker discovery and mechanism exploration for Chinese people. **Liu Mofang** proposed that human phenome research provides new ideas for the development of male infertility drugs.

二、全球表型组研究未来趋势

2. Future trends of global phenome research

研究方向上，应重点关注"基因-环境-表型"的关联解析。关联关系揭示了基因与环境之间的复杂互动，以及两者如何共同影响个体的生物特征。**田梅**指出，人类表型组研究核心在于揭示基因与环境对个体生物特征的综合作用。**瑞典卡罗林斯卡医学院教授、福建医科大学副校长叶为民和中国科学院大学杭州高等研究院生命与科学学院首席教授林旭**以肺癌、肥胖等疾病为例，强调

疾病发病取决于基因和环境共同作用。

In terms of research directions, priority should be given to the analysis of correlations among genes, the environment and phenotypes. Such correlations reveal complex interactions between genes and the environment, and how they affect individual biological traits jointly. **Tian Mei** pointed out that the core of human phenome research is revealing comprehensive effects of genes and the environment on individual biological traits. **Ye Weimin, professor at Karolinska Institute in Sweden and Vice President of Fujian Medical University, and Lin Xu, Chief Professor of the School of Life and Health Sciences, Hangzhou Institute for Advanced Study, University of Chinese Academy of Sciences,** emphasized that pathogenesis depends on combined effects of genes and the environment with lung cancer, obesity and other diseases as examples.

方法工具上，AI 深度赋能多维度数据的高效解析。莱诺·胡德指出，人工智能与大数据技术在表型组研究中至关重要，人工智能支持下的大数据技术不仅能帮助医生处理海量数据，还能提升诊断准确性，智能预测潜在疾病风险，将普通医生升级为具备长期健康管理能力的专家。**叶为民**指出，要做精细化的人群队列研究，获取不同尺度和更加精确的表型组数据，利用人工智能技术提高数据质量和分析准确性。**林旭**指出，需要结合多组学技术、人工智能技术和可穿戴设备，对个体的糖脂代谢、肠道菌群等多

维度数据进行精密测量和指标量化分析。

In terms of methods and tools, AI empowers the efficient analysis of multidimensional data deeply. Leroy Hood pointed out that artificial intelligence and big data technology are crucial in phenotype research; big data technology supported by artificial intelligence not only helps physicians process massive data, but also improves diagnostic accuracy, predicts potential disease risks intelligently, and turns ordinary physicians into experts with long-term health management capabilities. **Ye Weimin** pointed out that it is necessary to conduct refined population cohort research, obtain more accurate phenome data at different scales, and improve data quality and analytical accuracy using artificial intelligence technology. **Lin Xu** pointed out that it is necessary to conduct accurate measurement and quantitative indicator analysis of multidimensional data such as individual glycolipid metabolism and gut microbiota by integrating multi-omics technology, artificial intelligence technology, and wearables.

组织模式上，持续以国际大科学计划提升全球大协作能级。田梅介绍，人类表型组研究是一项系统化、集成化、工程化的研究，需要通过国际大科学计划这种全球大协作的方式来推进，实现对全世界不同区域的大规模人群用同一种标准尺度进行精密测量和系统解析，绘制“人类表型组参比图谱”，为未来生命科学探索提供一张全新的“导航图”。当前，一期计划已取得重大进展，

形成“四个一”的成效，即第一个跨尺度、多维度、一站式人类表型组精密测量平台、第一套多组学标准物质、第一个自然人群深度表型组队列、第一批人类表型组导航图。

In terms of organizational model, the level of global collaboration will be further improved through major international science programs. According to **Tian Mei**, human phenome research is a type of systematic, integrated and engineered research that should be promoted through global collaboration such as major international science programs to realize precise measurement and systematic analysis of large-scale populations in different parts of the world on the same standard scale, and draw a “human phenome reference map” that provides a new “navigational chart” for future life science exploration. Currently, significant progress has been made in the first phase of the program, and the outcome of “four firsts” has been achieved, namely the first cross-scale, multidimensional and one-stop precision measurement platform for the human phenome, the first set of multi-omics standard substances, the first deep phenome cohort for natural populations, and the first batch of human phenome navigational charts.

三、推进全球表型组研究的相关建议

3. Suggestions for promoting global phenotype

research

一方面，推进多领域深度融合，构建人类健康研究新范式。人类表型组研究亟须整合生物学、信息学、大数据等领域的技术力量，加速科学发现和技术突破。**田梅**认为，人类表型组研究的复杂性要求跨学科技术的深度融合，包括分子影像、空间组学等前沿技术的融入。**林旭**也指出，多组学与精准营养、精准健康结合将推动人类健康研究，有助于实现“个体到群体”的全方位健康管理。

On the one hand, promote the deep integration of multiple fields and create a new paradigm for human health research. There is an urgent need to integrate technological forces from fields such as biology, informatics and big data in human phenome research to accelerate scientific discoveries and technological breakthroughs. **Tian Mei** thought that the complexity of human phenome research requires the in-depth interdisciplinary integration of technologies, including frontier technologies such as molecular imaging and spatial omics. **Lin Xu** also pointed out that the combination of multi-omics with precision nutrition and precision health will promote human health research and help realize all-round health management from individuals to groups.

另一方面，强化数据开放政策引导和共享标准建设，实现全球研究数据全面共享。人类表型组研究的有效推进离不开全球范

围的数据共享。建立标准化的数据共享机制，制定相关法律和伦理规范，确保数据的统一性、安全性与合规性，是实现高效合作的重要保障。**叶为民**指出，通过建立大型生物样本库和全省医疗大数据连接，可以实现有效数据高度共享和长期随访，形成跨学科和跨区域的数据协作。**田梅**提出，人类表型组研究依赖统一标准与技术规范，确保各国科研工作实现顺利对接。**林旭**也认为，制定促进数据共享和标准化相关政策，对于产出高质量研究成果至关重要。

On the other hand, strengthen policy guidance for data openness and the formulation of sharing standards to realize the all-round sharing of global research data. The effective progress of human phenome research would have been impossible without global data sharing. Establishing a standardized data sharing mechanism, formulating relevant laws and ethical norms, and ensuring the uniformity, security and compliance of data is an important guarantee of efficient cooperation. **Ye Weimin** pointed out that establishing a large-scale biological sample library and connecting province-wide medical big data can realize effective data sharing and long-term follow-up, and establish interdisciplinary and cross-regional data collaboration. **Tian Mei** proposed that human phenome research relies on unified standards and technical specifications to ensure the smooth integration of scientific research work among countries. **Lin Xu** also thought that formulating

policies to promote data sharing and standardization is crucial for generating high-quality research findings.

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