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The Evolving Landscape of Biochemical Research: From Molecules to Medicine

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ABSTRACT

A transformation has taken place within biochemical research where out-dated practices of focusing on individual molecules and pathways without considering biological systems as a whole has changed to a practice where there is consideration for systems biology. This review looks at the history of biochemical research and trace the events that led to the innovation of the technology, their regards to changing paradigms research focus, as well as increased focus on translational research. To this end, an analysis of the transitions between classical biochemistry, modern systems biology, the effects of genomics, proteomics, metabolomics, and the shifting focus on drug and tailored medicine discovery via computation is presented.

Keywords: Medicine; Biological systems; Biomolecules.

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1. INTRODUCTION

Biochemical research has been the building blocks to understanding complex life processes for development of medicine, agriculture, biotechnology, etc. Starting from the observation and identification of simple biomolecules, the focusing has shifted to much bigger and complex webs and networks of interactions, and their relations within a cell. This systematic shift in scope can be attributed to an understanding of biological systems along with technological advancements.

2. The Era of Classical Biochemistry

The roots of metabolic processes are understood with the help of classical biochemistry that involves the isolation and characterization of enzymes, various pathways, and numerous biomolecules. [1, 2] The discovery of glycolysis, the citric acid cycle, and the distinctive vitamins and cofactors were major landmarks of this stage. [3, 4] Nevertheless, this reductionist perspective fails to account for the holistic nature of life.

3. The Rise of Molecular Biology and Genomics

Biochemical research saw an unprecedented change with the introduction of molecular biology marked by the discovery of the DNA structure and the advancement of recombinant DNA technologies. [5, 6] The field of genomics, which allows for complete sequencing and analysis of entire genomes, offered an unprecedented perspective regarding the essence of life. [7, 8] Thus, genes responsible for diseases were discovered and therapies based on genes were created. [9, 10]

4. Proteomics and Metabolomics: Expanding the Biochemical Landscape

Proteomics, which refers to the investigation of all expressed proteins in a cell or organism, along with metabolomics, which refers to the study of small molecule metabolites, have widened the dimensions of biochemistry research. These technologies reveal the changes of protein expression and

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metabolic activity that are provoked by physiological and pathological conditions [11-14] as shown in Fig (1).

5. Systems Biology and Network Analysis

The limitations of reductionism have led to the evolution of systems biology, a framework that emphasizes the study of biological systems as integrated networks. [16, 17] Network analysis (Fig 2), which uses computational approaches to model and study biological interactions, has become essential to understanding the complexity of cellular processes. [18, 19]

6. Computational Biochemistry and Drug Discovery

Molecular modeling and simulation, as key components of computational approaches, have matured in the biochemistry laboratory, especially in drug discovery efforts. [21, 22] These systems allow us to perform virtual drug candidate screenings, predict drug-target interactions, and design new drugs. [23, 24]. Fig. 3 illustrates the process of developing new drug.

7. Translational Biochemistry and Personalized Medicine

Translational biochemistry seeks to connect fundamental study and clinical application. Translational research focuses on personalized medicine, which aims to customize treatments for each patients according to their genetic and biochemical profiles [26- 30] as shown in Fig. 4.

8. Future Directions and Challenges

This work will empower biochemical research to decode the relationship between transient activities and chronic diseases by converging multiple data streams, constructing advanced mathematical models, and producing laboratory findings that translate to clinical information. You have to think about the ethical issues around gene editing and, very much, personalized medicine; you need to have robust data sharing and collaboration; and you have to have sustainable funding models. [31-38]

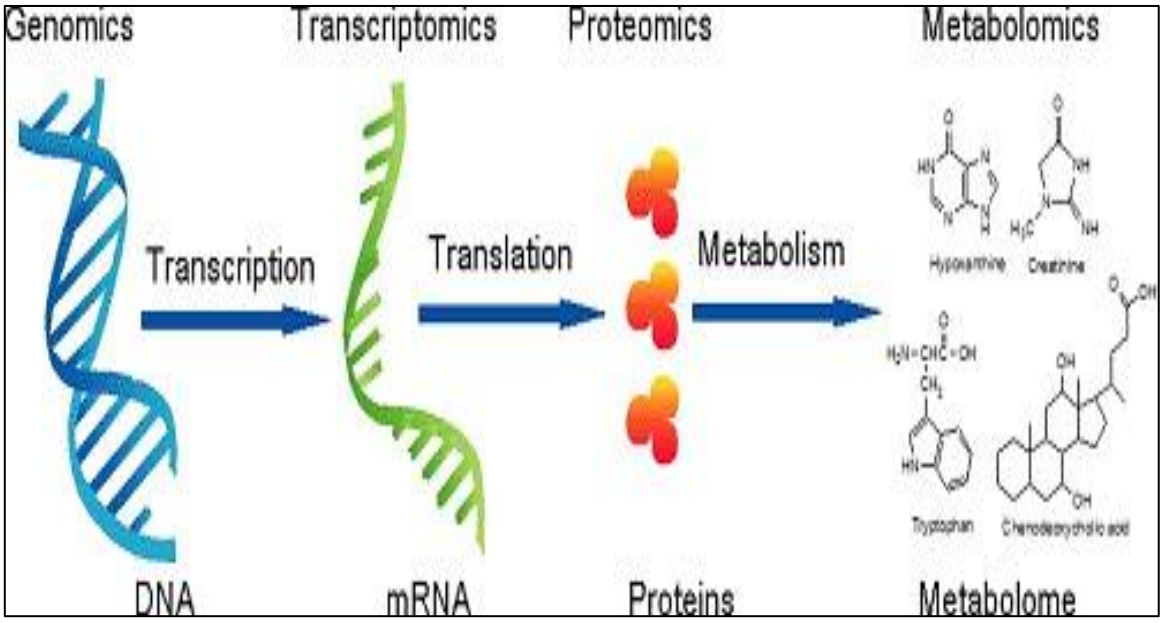

Figure 1: Application of Biochemistry in proteomics and metabolomics [15].

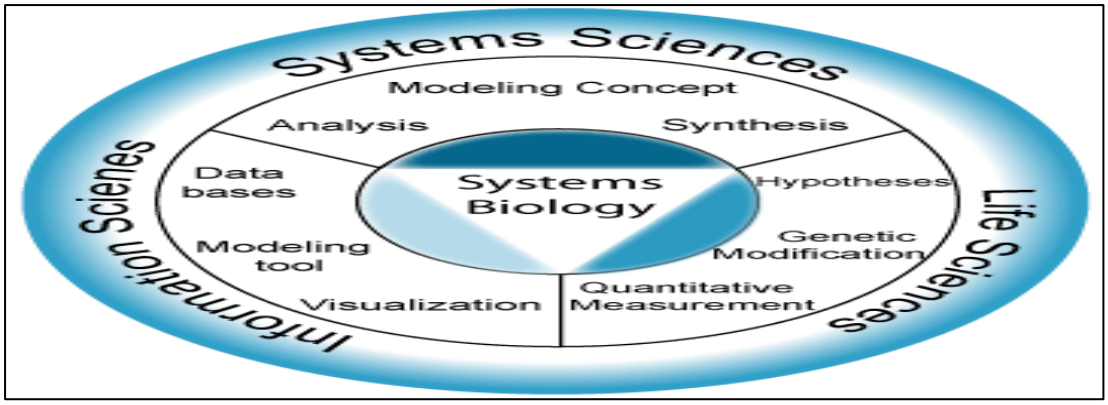

Figure 2: Role of Biochemistry in systems biology [20]

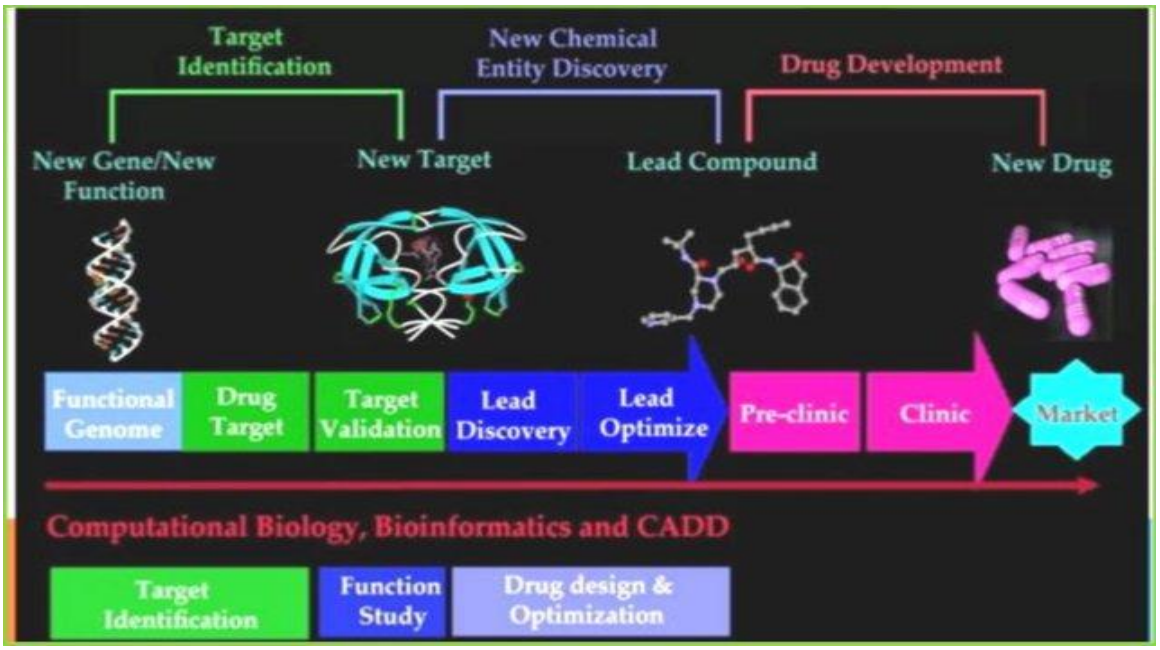

Figure 3: Integrated process of computational biochemistry in drug discovery [25]

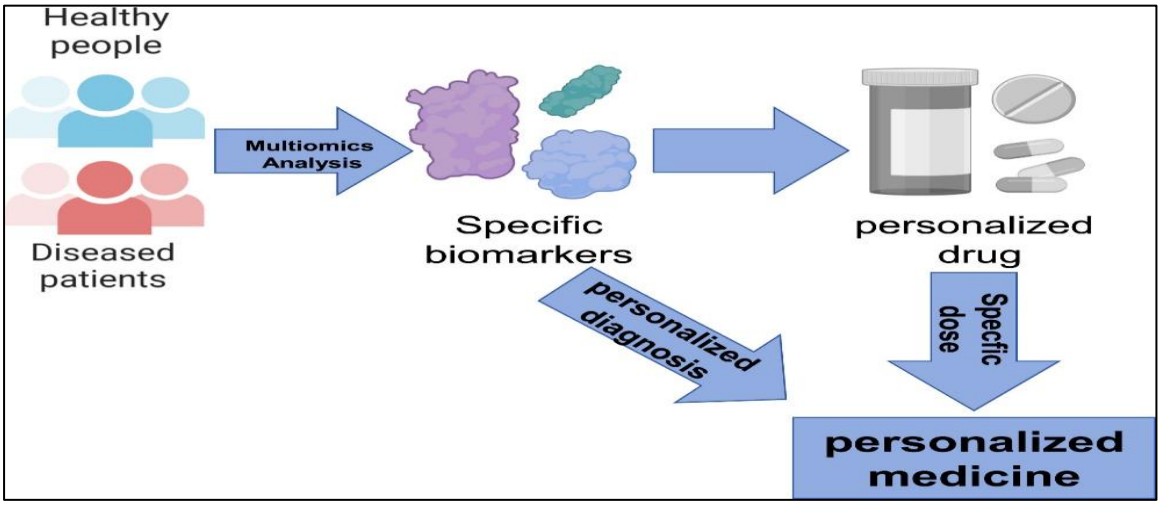

Figure 4: Process of developing personalized drugs [37]

CONCLUSION

This review has demonstrated the continuous evolution of biochemical research: Early studies investigated individual molecular components, and with growing databases and extensive computational resources, biochemical research has evolved into a broad systems-level view of biological processes. Advances in technology and a deeper understanding of biocomplexity enable the transition from classical biochemistry foundational discoveries to the genomics, proteomics, and systems biology era; however, new approaches are required to bring this genomic-generated functionality to practical utility. These computational approaches and the push for translational applications are steering personalized medicine and new drug discovery forward even faster. But the field has a lot of obstacles to overcome. Careful navigation is necessary to navigate the ethical issues surrounding gene editing and the responsible use of big data in personalized medicine. Maximizing the societal impact of biochemical research requires promoting interdisciplinary collaborations and guaranteeing fair access to state-of-the-art technologies. To fully utilize biochemistry in improving human health and well-being in the future, a persistent focus on innovation, data integration, and ethical responsibility will be necessary.

REFERENCES

1. Senior AW, Evans R, Jumper J, Kirkpatrick J, Sifre L, Green T, et al. Improved protein structure prediction using potentials from deep learning. *Nature*. 2020;577(7792):706–10. DOI:10.1038/s41586-019-1923-7

2. Brooks CL, Gruebele M, Onuchic JN, Wolynes PG. Chemical physics of protein folding. *Proc Natl Acad Sci* USA. 2001;98(1):1–2. DOI:10.1073/pnas.98.1.1

3. Krebs HA. Tricarboxylic acid cycle. *Enzymologia*. 1937;4:148–56.

4. Funk C. On the chemical nature of the substance which cures polyneuritis in birds induced by a diet of polished rice. *J Physiol*. 1912;45(1):485–9.

5. Watson JD, Crick FHC. Molecular structure of nucleic acids; a structure for deoxyribose nucleic acid. *Nature*. 1953;171(4356):737–8. DOI:10.1038/171737a0

6. Cohen SN, Chang AC, Boyer HW, Helling RB. Construction of biologically functional bacterial plasmids in vitro. *Proc Natl Acad Sci USA*. 1973;70(11):3240–4. DOI:10.1073/pnas.70.11.3240

7. Lander ES, Linton LM, Birren B, Nusbaum C, Zody MC, Baldwin J, et al. Initial sequencing and analysis of the human genome. *Nature*. 2001;409(6822):860–921. DOI:10.1038/35057062

8. Venter JC, Adams MD, Myers EW, Li PW, Mural RJ, Sutton GG, et al. The sequence of the human genome. *Science*. 2001;291(5507):1304–51. DOI:10.1126/science.1058040

9. Kay MA, Glorioso JC, High KA. Viral vectors for gene therapy: the art of turning infectious agents into vehicles of therapeutics. *Nat Med*. 2001;7(1):33–40. DOI:10.1038/83389

10. Mulligan RC. The basic science of gene therapy. *Science*. 1993;260(5110):926–32. DOI:10.1126/science.8493530

11. Aebersold R, Mann M. Mass spectrometry-based proteomics. *Nature*. 2003;422(6928):198–207. DOI:10.1038/nature01511

12. Nicholson JK, Lindon JC, Holmes E. ‘Metabonomics’: understanding the metabolic responses of living systems to

pathophysiological stimuli via NMR spectroscopy-based pattern recognition. *Xenobiotica*. 1999;29(11):1181–9. DOI:10.1080/004982599238047

13. Yates JR, Ruse CI, Nakorchevsky A. Proteomics and systems biology. *Annu Rev Anal Chem*. 2009;2:49–68. DOI:10.1146/annurev-anchem-060908-155239

14. Fiehn O. Metabolomics—the link between genotypes and phenotypes. *Plant Mol Biol*. 2002;48(1):155–71. DOI:10.1023/A:1013713905833

15. Zhao YY, Lin RC. UPLC–MSE application in disease biomarker discovery: The discoveries in proteomics to metabolomics. *Chem Biol Interact*. 2014;215:7–16. DOI:10.1016/j.cbi.2014.02.014

16. Ideker T, Galitski T, Hood L. A new approach to decoding life: systems biology. *Annu Rev Genomics Hum Genet*. 2001;2(1):343–72. DOI:10.1146/annurev.genom.2.1.343

17. Kitano H. Systems biology: a vision and perspective. *Science*. 2002;291(5507):1251–2. DOI:10.1126/science.1059927

18. Barabási AL, Oltvai ZN. Network biology: understanding the cell's functional organization. *Nat Rev Genet*. 2004;5(2):101–13. DOI:10.1038/nrg1272

19. Shatha R. Zaidan, Julia J. Schüer, (2024) Interaction studies of Insulin Degrading Enzyme (IDE) with a model membrane. *Frontiers in Health Informatics*, 13 (4), 757-774

20. Jeong H, Tombor B, Albert R, Oltvai ZN, Barabási AL. The large-scale organization of metabolic networks. *Nature*. 2000;407(6804):651–4. DOI:10.1038/35036627

21. Gutiérrez RA, Shasha DE, Coruzzi GM. *Systems Biology for the Virtual Plant*. Plant Physiol. 2005;138(2):550–4. DOI:10.1104/pp.104.900150

22. Jorgensen WL. The many roles of computation in drug discovery. *Science*. 2004;303(5665):1813–8. DOI:10.1126/science.1096361

23. Shoichet BK. Virtual screening of chemical libraries. *Nature*. 2004;432(7019):862–5. DOI:10.1038/nature03197

24. Sana F, Ayesha J, Talath F, Sharequa H. Computational Drug Designing of Anticancer Drugs. *Int J Pharm Res Scholars*. 2018;7(2):58–70. DOI:10.31638/IJPRS.V7.I2.00032

25. Kitchen DB, Decornez H, Furr JR, Bajorath J. Docking and scoring in drug discovery: methods and applications. *Nat Rev Drug Discov*. 2004;3(11):935–49. DOI:10.1038/nrd1549

26. Kuhlman B, Bradley P. Advances in protein structure prediction and design. *Nat Rev Mol Cell Biol*. 2022;23(5):329–45. DOI:10.1038/s41580-022-00473-y

27. Jumper J, Evans R, Pritzel A, Green T, Figurnov M, Ronneberger O, et al. Highly accurate protein structure prediction with AlphaFold. *Nature*. 2021;596(7873):583–9. DOI:10.1038/s41586-021-03819-2

28. Lander ES, Linton LM, Birren B, Nusbaum C, Zody MC, Baldwin J, et al. The Human Genome Project: Lessons from large-scale biology. *Science*. 2021;372(6537):eabk0103. DOI:10.1126/science.abk0103

29. Hasin Y, Seldin M, Lusis A. Multi-omics approaches to disease. *Genome Biol*. 2020;21(1):83. DOI:10.1186/s13059-020-01994-5

30. Regev A, Teichmann SA, Lander ES, Amit I, Benoist C, Birney E, et al. The Human Cell Atlas. eLife. 2021;10:e66747. DOI:10.7554/eLife.66747

31. Mullard A. FDA drug approvals in 2022. *Nat Rev Drug Discov*. 2023;22(2):83–8. DOI:10.1038/d41573-023-00001-3

32. Sahin U, Türeci Ö. mRNA-based therapeutics—developing a new class of drugs. *Nat Rev Drug Discov*. 2021;20(10):735–6. DOI:10.1038/d41573-021-00079-7

33. Su J, Yang L, Sun Z, Zhan X. Personalized Drug Therapy: Innovative Concept Guided With Proteoformics. *Mol Cell Proteomics*. 2024;23(3):100737. DOI:10.1016/j.mcpro.2024.100737

34. Doudna JA, Charpentier E. The new frontier of genome engineering with CRISPR-Cas9. *Science*. 2020;346(6213):1258096. DOI:10.1126/science.1258096

35. Frangoul H, Altshuler D, Cappellini MD, Chen YS, Domm J, Eustace BK, et al. CRISPR-Cas9 gene editing for sickle cell disease and β-thalassemia. *N Engl J Med*. 2021;384(3):252–60. DOI:10.1056/NEJMoa2031054

36. Stokes JM, Yang K, Swanson K, Jin W, Cubillos-Ruiz A, Donghia NM, et al. A deep learning approach to antibiotic discovery. *Cell*. 2020;180(4):688–702. DOI:10.1016/j.cell.2020.01.021

37. Mitragotri S, Anderson DG. Innovations in biomaterials for drug delivery. *Nat Rev Mater*. 2023;8(1):1–20. DOI:10.1038/s41578-022-00513-1

38. Al-Ziaydi AG. Evaluation of D-Mannoheptulose and Doxorubicin as Potential Therapeutic Agents for Breast Cancer by Targeting Glycolysis and Inducing Apoptosis. Indian Journal of Clinical Biochemistry. 2024 Sep 11:1-0. https://doi.org/10.1007/s12291-024-01266-0

39. Kadooh QA, Al-Ziaydi AG, Hamza AJ. Evaluation of the influence of trastuzumab therapy on serum levels of HER-2 protein and breast cancer cell lines. Menopause Review/Przegląd Menopauzalny.;23(1). DOI:https://doi.org/10.5114/pm.2024.139607

