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Bridging Gaps and Directing Future Innovations: Revisiting the Contribution of Biochemistry in Improving Clinical Management

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Review Article

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ABSTRACT

Aims: to review the contributions of biochemistry and its clinical applications in patients management.

Discussion: Advanced health professionals and their healthcare delivery nowadays rely essentially on basic biochemistry and its clinical application for understanding the pathophysiology of disease. Those doctors can make a definite diagnosis with best therapeutic option, pharmacologically and non-pharmacologically, all made available with strong basic and applied knowledge and by doing so, giving significant clinical benefits for the patient and also the best practice of clinical management. Classic daily problem encounters including operational restrictions, *e.g.*, the sum of clinical sample delivered is way too scanty, equipment incompatibility, technique's precision hindrances, and unsupported financial difficulties. Recent advancements in established technologies and apply it on clinical setting mass service, such as advance spectrometry and the buildout of state of the art high-throughput screening and basically point-of-

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care technologies such as current biosensor technology and wearable monitors which facilitate continuous health tracking are the role of Biochemistry in clinical management advancement. The application of these sophisticated biochemistry approaches is actually transforming the face of clinical service on to a more modern, reliable and accountable clinical management. Machine learning (ML) and Artificial Intelligence (AI) applications enhance analytical capabilities based on wide array of clinical proven data and allowing more room for predictive insights for individualized treatment protocols. Concerns regarding achievements and its dynamic limitation, including ethical issues always pose significant challenges. It must be addressed for more responsible integration between basic science and clinical management conducted by doctors and hospitals. Interprofessional colaboration ensure fairness and responsible health service while at the same time identifying research priorities to enhance diagnostic precision and better accessibility for superior healthcare delivery, such can be seen in tropical diseases management, cancer treatment, genetic disorders and metabolic diseases.

Keywords: Medical intervention; solution; patient; interprofessional; biosensor; ML/AI; tropical disease; cancer; genetic; metabolic.

1. INTRODUCTION

Biochemistry serves as the fundamental basis of modern medicine (Cao, et al., 2025) and healthcare (Mureyi, 2023). Clinical biochemistry basically provides a molecular apprehension of homeostatic processes which if disturbed by various internal (due to aging) or external (due to infection) factors may explain (1) disease formation which arises from disruptions in normal cellular biochemical processes, such as gene expression errors, metabolic imbalances from nutrient deficiencies or excesses, or the accumulation of misfolded proteins like amyloid fibrils (Mentis & Dalamaga, 2025), (2) correct and reliable diagnosis by identifying disease-specific biomarkers in bodily fluids, such as elevated enzymes or abnormal hormone levels, to diagnose and monitor conditions (Das et al., 2025; Monaghan, et al., 2016), (3) treatment and prevention method where Biochemistry incorporates elements of pharmacology, pathology, cell biology, and physiology to explain the basis and proposed therapeutic options for the prevention and treatment of diseases, understanding biochemical processes allows for proactive health interventions and the identification of lifestyle factors and nutrients with preventive properties (Silva, 2023).

Those biochemistry techniques when can be applied to all condition, from pathogenesis, diagnosis, treatment and prevention, enable health professionals to identify biochemical imbalances as underlying condition of disease (Bustin & Jellinger, 2023; Barr, 2018). Beside that, it can also be implemented in the development of biomarkers or small molecule metabolites as targeted drugs (Qiu, et al., 2023; Monaghan, et al., 2016), the creation of advanced diagnostic tools, e.g., in cancer (Pulumati, et al., 2023), infectious disease (Wang, et al., 2024), neurodegenerative disease and depression (Shusharina, et al., 2023), genetic disease (Dwivedi, et al., 2024), etc. Other aspects benefited from biochemistry including improving lab tests that measure key molecules like glucose as in the form of glucose biosensor (Pullano, et al., 2022) and detecting cholesterol level using wireless non-invasive monitoring inserted in a smart contact lens (Song, et al., 2022).

By carefully studying the chemical reactions within cells, tissue and organs as the important basis for normal function of life (Pandey, 2024), medical biochemists translate basic scientific discoveries into clinical applications, also known as translational research or the bench-to-bedside process (Seyhan, 2019), contributing to advancements in the field involving personalized medicine (Lattanzi, et al., 2021), nutritional science (Neufeld, et al., 2023), organ derangement such as atrial fibrillation (Nattel et al., 2021) and the race against antibiotic-resistance (Caioni, et al., 2024) especially in improving clinical management through careful and responsible implementation of science (Finney Rutten, et al., 2024).

Health professionals relies essentially on basic biochemistry and its clinical application for understanding the pathophysiology of disease; thereby making definite diagnosis with best therapeutic option, both pharmacologically and non-pharmacologically. This mini review will discuss the contribution of basic biochemistry and its clinical application in patient's clinical management through implementation science.

2. CLINICAL MANAGEMENT: PERSPECTIVE AND PROBLEMS

Clinical management refers to the coordinated approach towards the delivering of the best healthcare services, effectively and efficiently. Clinical management best practice involves using evidence-based clinical practice guidelines (CPGs) aimed primarily to hone patient care (Guerra-Farfan et al., 2023). CPGs are systematically and carefully reviewed recommendations for treating specific conditions, conducted periodically by critical contributors to clinical decision making. CPGs based on a thorough scientific base scrutiny and combined with comprehensive analysis of the finest convenience scientific evidence and an assessment of alternative care options (Mancin, et al., 2023).

Unfortunately, out of those ideal definition of best practice clinical management, classic daily problem encountered including operational restrictions regarding clinical sample management, e.g., the lack of standardization in collection kits, logistical complexities in transport and storage, increased time and resource burdens, a higher risk of errors in sampling and documentation, and difficulties in scalability for trials with more sites or complex needs, equipment incompatibility, technique's precision hindrances, and unsupported financial difficulties (Redrup, et al., 2016).

Operational restrictions, such as lack of resources, bureaucracy, lack of training and inadequate IT or digitalization infrastructure (Sasaki, et al., 2020), which even reported from develop country like Germany (Shehu, et al., 2024), where it can significantly hinder the implementation of best clinical management practices by limiting staff capacity (Zajac, et al., 2021), imminent necessary processes, and slowing down access to essential innovations (Al-Saleem & Aldakheel, 2024). These operational barriers lead to heightened medical errors (Sharma & Cotton, 2023; Rodziewicz, et al., 2025), reduced quality of physician's work (Sinnott, et al., 2020), poor patient outcomes (Kumah, 2025) and reduced quality of care (Sharma & Cotton, 2023) by creating an environment where evidence-based recommendations cannot be effectively integrated into routine daily practice (Pitsillidou, et al., 2023). One of the common condition found regarding operational restriction or resource constraint was the amount of clinical sample sent for examination was very limited (Crimmin, et al., 2019). A clinical sample can be part of operational restrictions when the risk of sample re-identification from sensitive data or potential harm to participants outweighs the benefit of sharing for scientific discovery, or when operational burdens limit sample handling (Hansson, et al., 2016). Restrictions also apply to mandatory sample retention (Wendler, 2021). Those limitation of sample management itself due to legal, proprietary, legislative, and ethical complexities (O'Hare, et al., 2022).

A limited amount of clinical samples delivered to a lab impacts clinical management by potentially causing delays in diagnosis and treatment (van Moll, et al., 2023), leading to inaccurate or unexpected laboratory test results (Masood & Karim, 2020), increased or unwanted additional costs from re-testing (Bozdemir, et al., 2022), and ultimately compromised patient care, including misdiagnosis or incorrect treatment (Lam & Church, 2024). Addressing this requires improving sample collection, e.g., by using the aid of a multi-modal routing algorithm (Oakey, et al., 2023), keeping the best practice of handling protocols (Ricciardi & Cascini, 2021), enhancing staff with specific training that will empower their competence and service, e.g., with in service training for nurses (Chaghari, et al., 2017), implementing better logistics and quality control within the laboratory to ensure the integrity and validity of the samples and the data derived from them, including equipment issues (Pillay, et al., 2025; Chaudhry, et al., 2023).

Equipment incompatibility directly compromise best practices in clinical management by leading to patient harm, such as misdiagnosis or treatment error, and decreased efficiency through workflow disruptions and wasted time (Altayyar, 2020). It necessitates the use of specialized, compatible equipment for patient and staff safety (Elnitsky, et al., 2014). Effective management requires comprehensive policies for equipment procurement, including compatibility checks, user training and regular maintenance, to prevent integration issues and ensure reliable, safe, and efficient patient care (Zamzam, et al., 2021). This equipment issues may have followed with obstacles regarding the precision of medical technique used and its comprehensiveness for the specialized genre of the hospital service (Woldeyohanins, et al., 2025).

Technique precision, one of which can be applied through precision metrics, is critical for best practice in clinical management (Woldeyohanins, et al., 2025; Lastrucci, et al., 2024), as its absence leads to medical errors, reduced patient safety, and suboptimal care (Alharbi, et al., 2025). Barriet to this precision implementation, including lack of training for staff who operate the equipment (Khan, et al., 2025), inadequate resources or system failures (Kumah, 2025; Alharbi, et al., 2025) will surely compromises quality and necessitating systematic quality improvement processes (Pulumati, et al., 2023), the implementation of tools like clinical decision support systems (Sutton, et al., 2022), which is a valuable tools in healthcare settings to enable clinicians to make informed decisions and improve patient outcomes. Beside that, it is highly recommended to establish a culture that encourages reporting errors to facilitate evidence-based process changes (Chance, et al., 2024). All of those previously mentioned problems have cost, and these costs sometimes also have to be borne by the patient.

unsupported financial difficulties negatively impact best practices in clinical management by forcing cost-cutting measures like reducing staffing, delaying technology investments, and lowering service quality, which can lead to reduced compliance with standards and potentially hospital closures (Pisu & martin, 2022). Healthcare debts, or financial strain which also limits patients' access to essential healthcare, causing delayed or forgone services due to barriers to access and out-of-pocket costs, ultimately widening health disparities and pushing families into poverty (Aborode, et al., 2025; Shehu et al., 2025).

3. THE CONTRIBUTION OF BIOCHEMISTRY IN EFFORTS TO ERADICATE HEALTH PROBLEMS

Biochemistry plays a pivotal role in modern medicine by providing insights into the biochemical pathways that underlie various diseases. Understanding these pathways is crucial for developing new strategies for disease prevention and treatment (Cao, et al., 2025; Mureyi, 2023; Silva, 2023). For instance, biochemists investigate the causes and cures of diseases by studying the chemical processes within living organisms (Barr, 2018), which helps in the screening, diagnosis, monitoring, and management of human diseases (Cao, et al., 2025; Mureyi, 2023; Silva, 2023). This includes specialized investigations for measuring hormones (Lai & Mueller, 2025), cancer markers (Zhuo, et al., 2024), vitamins (Lykstad & Sharma, 2025; Reddy & Jialal, 2022), biological trace elements (Attar, 2020), drugs development (Gour, 2023) and specific proteins, especially in the context of site specific functionalization and its application as therapeutic antibodies (van Vught, et al., 2014). These achievements are essential for diagnosing and monitoring conditions such as cancer (Ando, et al., 2021), genetic disorders (Mentis & Dalamaga, 2025) and metabolic diseases (Islam, et al., 2024).

Recent advancements in health or medical device including established state of the art technologies and apply it on clinical setting mass service, such as advance mass spectrometry (Das, et al., 2025; Son, et al., 2024) and the buildout of state of the art high-throughput screening and basically point-of-care technologies such as current biosensor technology (Hemdan, et al., 2024; Pullano, et al., 2022). biosensor is a device that integrates a biological element (like an enzyme or antibody) with a transducer and electronics to detect and measure specific biological or chemical substances (analytes). It converts a biological response into a measurable signal, such as an electrical current or a color change, which can then be displayed or recorded. Biosensors are used in various fields, including medicine for disease diagnosis, environmental monitoring, and food safety (Hemdan, et al., 2024; Pullano, et al., 2022; Bravo-Merodio, et al., 2021; Bhalla, et al., 2016). On a more specific scope, a wide range of techniques can be used for the development of biosensors (Bravo-Merodio, et al., 2021). Their coupling with high-affinity biomolecules allows the sensitive and selective detection of a range of analytes (Bhalla, et al., 2016). The expansion of current biomolecular sensing strategies combined with the application of nanotechnological approaches is still very possible along with the latest findings or breakthroughs in the field of molecular biochemistry.

Another Thing Worth Mentioning is the advancement and widely application of wearable monitors or biosensor which ensure continuous health monitoring (Kharb, 2025). The application of these sophisticated biochemistry approach is actually transforming the face of clinical service on to a more modern, reliable and accountable clinical management (Cao, et al., 2025).

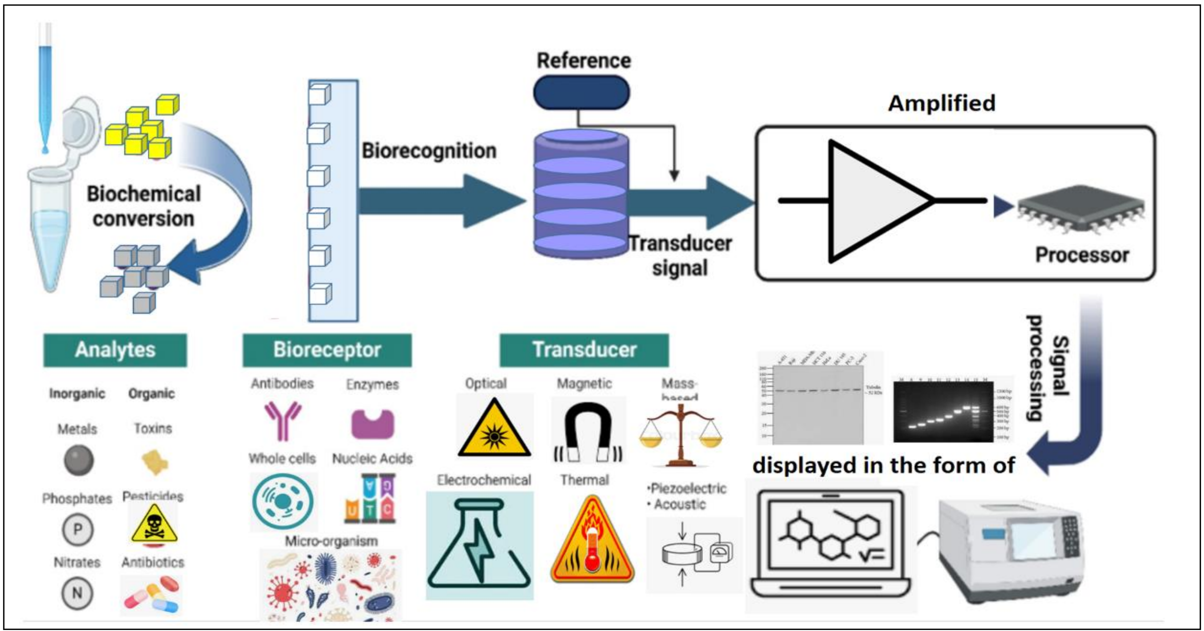

Fig. 1. Steps in Biosensor (Hemdan, et al., 2024 with modification). A biosensor works on the principle of biorecognition and signal transduction. It uses a biological recognition element, such as an enzyme or antibody, to specifically interact with a target substance (analyte). This interaction produces a biological response, which is then converted into a measurable signal (electrical, optical, or other) by a transducer. This signal is then amplified and processed to provide a quantitative or semi-quantitative result, often displayed for analysis. The implementation of biochemical principles into ready-to-use machines that can be used daily is an example of the contribution of biochemistry to improving clinical management

4. RECENT RELIABLE BIOCHEMISTRY-RELATED TECHNOLOGIES FOR CLINICAL MANAGEMENT

Modern clinical management has shifted to the area towards a more patient-centered attitude and driven by the combination of medical technology for more personalized and precision medicine (Ho, et al., 2020; Mills, 2017), big data (Badr, et al., 2024) and interprofessional team-based care (Thacharodi, et al., 2024; Cadet, et al., 2023). Empirical evidence indicates that collaborative interprofessional practice leads to positive health outcomes (Cadet, et al., 2023).

Key shifts include: (1) the application of artificial intelligent (AI) based devices for diagnosis (Al-Antari, 2023) and monitoring (Tsvetanov, 2024) (2) a greater emphasis on patient empowerment and autonomy (Hickmann, et al., 2022), and the integration of genetics sometimes called genomic medicine) (Khan, et al., 2025) and biotechnology (Ward, 2024) for individualized treatment. This results in a smooth progress from traditional, silent practices to a more open, integrated, data-driven, and collaborative healthcare system.

Biochemically, advanced spectrometry in clinical management, particularly mass spectrometry (MS), uses its high sensitivity and specificity to analyze biomolecules like proteins, metabolites and drugs for improved clinical management, offering enhanced disease diagnosis, personalized treatment monitoring, and drug development (Son, et al., 2024). Techniques such as liquid chromatography-mass spectrometry (LC-MS) can separate complex biological samples, enabling the identification and quantification of biomarkers and therapeutic drug levels (Alanazi, 2025). Applications range from (1) screening (Vaiano, et al., 2021), (2) therapeutic drug monitoring (e.g., in tuberculosis management) (Thu, et al., 2024) (2) explore disease mechanisms through proteomics and metabolomics (Zhang, et al., 2022); all bringing precision medicine closer to daily and routine clinical practice.

Biochemical properties in precision medicine are primarily represented by biomarkers (Das, et al., 2025; Mills, 2017; Zhou et al., 2024) which can be genomic (Kaur, et al., 2023), proteomic from urine or serum sample (Shama, et al., 2023) or other molecular signatures (Lahorewala, et al., 2025); and further analyzed through molecular diagnostics and integrated into clinical practice via pharmacogenomics (Qahwaji, et al., 2024). Routine clinical adoption of these properties requires advancements and integration in data analytics, sequencing technology and bioinformatics to interpret enormous quantity of data effectively and efficiently, along with the formation of vigorous biomarker databases and clinical guidelines to standardize their application in tailoring treatments for personalized patient and in screening and monitoring patient responses by using current biosensor technology and wearable monitors which facilitate continuous health tracking (Restrepo, et al., 2023).

The biochemical insight of the process regarding buildout of state of the art high-throughput screening (HTS) which uses automation and miniaturization to rapidly test large numbers of compounds for drug discovery and biochemical analysis (Faisal Bokhari & Albukhari, 2022), while Point-of-care (POC) technologies provide rapid, on-site diagnostic testing to inform clinical management decisions (Aborode, et al., 2025) beyond what traditional labs can ordinarily do. POC using automated systems to rapidly test large libraries of compounds for their effects on specific biological targets, often through biochemical assays that detect molecular interactions (McSwiggen, et al., 2025), while POC technology focuses on miniaturized, integrated biochemical assays to provide rapid, on-site diagnostic results. Key biochemical techniques include fluorescence-based assays, such as Fluorescence Resonance Energy Transfer or FRET (Xu, et al., 2024) and TR-FRET (Yue, et al., 2023), binding assays such as NMR, SPR and mass spectrometry (Larkins & Thombare, 2023), and cell-based assays that measure viability, reporter gene activation, or second messenger production (Tada, et al., 2014).

Machine Learning (ML) and Artificial Intelligence (AI) applications actually made possible in this era of best practice of clinical management. Advancements in artificial intelligence (AI) and machine learning (ML) are rapidly transforming the landscape of biochemical and molecular diagnostics. These technologies have demonstrated exceptional capabilities in processing large-scale omics data (Zhang et al., 2025), identifying exquisite biomarker patterns (Alum, 2025) and enhancing diagnostic accuracy across a wide range of diseases (Ahsan, et al., 2022). Current AI/ML applications in biochemical and molecular diagnostics, highlighting their integration in laboratory test interpretation, metabolomics profiling, genomic variant annotation, and transcriptomic analysis (Quazi, 2022). The expanded role of machine learning algorithms incorporating support vector machines, random forests, and deep neural networks in enabling predictive, high-throughput, and personalized diagnostics. Future directions regarding the transformative potential of AI and ML in advancing precision diagnostics and personalized medicine is a very good example of contribution of modern biochemistry to the advancement of clinical management, which can be seen in these following section

4.1 Tropical Diseases

Recent biochemical contributions to tropical diseases include the improvement of nanobiosensors which are recently used to detect parasitic infections (Sadr, et al., 2025), identifying new drug targets by studying parasite metabolism and mitochondrial functions as tried on malaria (Hikosaka, et al., 2015), developing novel diagnostic tools like quantitative PCR assays for parasitic DNA (Liu, et al., 2025), creating new drug candidates and treatments through medicinal chemistry focusing on heterocyclic compounds and natural products, e.g., through advancing drug discovery through structure-activity relationships (Chaudhary, et al., 2025) and advancing vaccine development by characterizing parasitic antigens and immune responses (Daga, et al., 2022).

4.2 Cancer Treatment

Recent biochemical approaches in cancer treatment (Pulumati, et al., 2023) with focus on precision oncology through specific and targeted therapies (Tilak, et al., 2023), utilizing next-generation sequencing to identify specific molecular aberrations (Galeș, et al., 2025) and design personalized treatments, such as kinase inhibitors and monoclonal antibodies (Fayyaz, et al., 2024). Other promising strategies which can be mentioned include nanomedicine for targeted drug delivery (Shekhar Dey, et al., 2024), advanced delivery systems like biopolymer-based aerogels or other nanoplatforms (Maspes, et al., 2021), and targeting novel cellular pathways like ferroptosis to induce cancer cell death (Saxena, et al., 2024). These smart approaches actually directed to increase treatment efficacy while minimizing damage to healthy cells. These alternatives literally transforming cancer care into a more personalized and less invasive medical option.

4.3 Genetic Disorders

Biochemistry contributes to understanding genetic disorders by revealing how genetic mutations disrupt molecular pathways, leading to disease (Mentis & Dalamaga, 2025). This understanding is used for diagnosing disorders through biochemical testing, developing targeted therapies like gene therapy, and enabling personalized medicine (Dwivedi, et al., 2024). Biochemists study the altered proteins, enzyme functions, and metabolic imbalances caused by genetic defects, which are key to designing effective treatments (Das, et al., 2025).

4.4 Metabolic Diseases

Biochemistry provides the framework for understanding how disruptions in metabolic pathways and cellular processes lead to diseases like diabetes, obesity, and metabolic syndrome (Clemente-Suárez, et al., 2023) By studying the biochemistry of metabolites, enzymes, and hormonal regulation—such as insulin resistance, dyslipidemia, and inflammation—biochemists identify the root biochemical causes of these diseases, discover biomarkers for prediction, and develop targeted therapies by manipulating these metabolic pathways (Islam, et al., 2024).

Concerns regarding these achievements and its dynamic limitation, including ethical issues such as over-reliance, bias, incompatibility, risk of exposure regarding data privacy and lack of transparency in decision-making always pose significant challenges that must be addressed for more responsible integration between basic science and clinical management conducted by doctors and hospitals which must ensure fairness and responsible health service while at the same time identifying research priorities to enhance diagnostic precision and better accessibility for superior healthcare delivery. Future recommendation including enhancing interprofessional collaboration which ensure fairness and responsible health service. Periodically remap the achievements and challenges still faced in determining the best clinical management will also help in settling the research priorities, especially in the context of enhancing diagnostic precision and improving accessibility for superior healthcare delivery, such can be implemented in the area of tropical diseases management, cancer treatment, genetic disorders and metabolic diseases.

5. CONCLUSION

Biochemistry advancements have dramatically improved clinical management through better understanding of disease mechanisms, development of targeted drugs and diagnostic tests, and the creation of personalized treatment plans. By analyzing biomarkers in bodily fluids, biochemists provide essential data for diagnosis, monitoring disease progression, and guiding therapies for conditions ranging from diabetes to cancer. These insights enable more precise interventions, leading to improved patient outcomes and the potential for personalized and targeted medical care. Even though there is always limitation which must be overcome by continuously explore the grey area in medicine with evidence based research (Pillay, et al., 2025).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that no generative AI technologies such as large language models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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