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Implications of Biochemical Research for Nursing Education: Review

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Abstract

Background: The study of metabolic changes in biological systems, or metabolomics, is a new subject that sheds light on the causes of illness and its effects on health. The evolution of nursing science necessitates the integration of metabolomics into research to improve patient care via personalized interventions.

Methods: This comprehensive review evaluates the metabolomics research conducted by nurse scientists over the past three decades. This work emphasizes developments in metabolomics methodologies, encompassing both untargeted and targeted approaches, while also analyzing the contributions of nurse researchers in this field.

Results: Although they make up a tiny portion of the larger scientific community, the review shows that nurse scientists are becoming more involved in metabolomics research. The primary findings suggest that the majority of studies are hypothesis-generating and depend on existing specimens instead of prospective collections, potentially constraining their rigor.

Conclusion: Future research should support multidisciplinary partnerships, improve educational curricula to include metabolomics training, and give priority to hypothesis-testing studies in order to fully realize the promise of metabolomics in nursing. Nurse scientists can significantly enhance the understanding of metabolic responses across diverse health conditions, thereby improving patient outcomes.

Keywords: Personalized medicine, metabolomics, nursing science, hypothesis testing, and multidisciplinary cooperation.

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1. Introduction

Systems biology and omics methodologies are essential for elucidating biological mechanisms in diverse health conditions. These methodologies improve the advancement of precision health, which employs various biomedical data to tailor patient care (1). Systems biology is a scientific discipline that utilizes advanced computational methods and high-throughput technologies to explore intricate biological systems across various levels, such as cellular, tissue, organ, and whole organism (2). This research focuses on omics approaches that analyze cellular molecules, including genes, epigenetic markers, transcripts, proteins, and metabolites, within biological systems, collectively termed the omics cascade. This analysis seeks to clarify the complex interactions present in biological systems. In the last ten years, advancements in tools for sensitively measuring multiple substances in biological samples, combined with enhancements in computational biology and high-throughput analytics, have enabled the analysis of complex biological systems (3, 4).

Omics approaches provide researchers with significant flexibility regarding the biological systems and specimen types that can be analyzed. These methods can be utilized to explore molecular mechanisms at the level of individual cells, tissues, or organs (5, 6). Biological specimens used in omics studies are varied, including blood components (e.g., serum or plasma), skin, hair, urine, saliva, and additional samples. Nurse scientists are making significant contributions to systems biology by conducting research across the omics cascade.

2. Metabolomics

Metabolomics is a relatively recent omics technique that allows nurse scientists to thoroughly investigate the comprehensive responses of living systems to various biological, behavioral, and environmental factors, elucidating the interactions among metabolites and metabolic pathways. This is consistent with the nursing research perspective, which aims to integrate individual experiences to create a scientific basis for clinical practice that prioritizes personalized care (7). This scoping review aims to analyze and summarize metabolomics studies conducted by nurse scientists, highlighting advancements in nursing science within this domain and offering direction for future research efforts.

Metabolomics is the comprehensive study of metabolites within biological systems, focusing on the identification and quantification of small molecules that reflect metabolic changes. This field integrates analytical chemistry, bioinformatics, and systems biology to elucidate metabolic pathways and their alterations in various conditions.

Metabolomics involves the measurement of low-molecular-weight molecules in specific tissues or cells (6) to identify individual molecules and their functions in cellular metabolism. Cellular metabolism includes all biochemical processes occurring within a living organism, involving essential molecules such as carbohydrates, fatty acids, and amino acids. The biochemical processes involved in the synthesis and degradation of molecules, along with the elimination of cellular waste, can be structured into interconnected pathways and their corresponding metabolites . Disruptions in metabolic pathways, known as perturbations, arise when specific metabolites demonstrate abnormal biochemical activity. These perturbations indicate an organism's intricate responses to disease conditions (8). Metabolomics enables researchers to evaluate the biochemical system's response to diseases or environmental exposures, elucidating mechanisms of physiological adaptation at a specific time or throughout a longitudinal study, contingent on the study design. The exposome concept, emphasizing the measurement of metabolites associated with environmental factors like diet and toxin exposure, has recently emerged in metabolomics (9).

The increasing focus on metabolomics arises from its capacity to illustrate the complex responses of biological systems to various internal or external stimuli, thereby aligning closely with clinical phenotypes in both human and animal models. In contrast to conventional clinical laboratory tests and biomarker assays, metabolomics enables the evaluation of thousands of distinct metabolites from a single sample (10). Additionally, metabolomic analyses can employ biofluids that are more readily collected from participants, including expelled breath and saliva (11, 12). Metabolites assessed may be endogenous or exogenous, rendering metabolomics an essential approach for elucidating various phenomena, including environmental exposures and cellular physiology (5, 13).

3. Lipidomics and Its Significance

Lipidomics, a distinct branch of metabolomics, emphasizes the quantification of individual lipid molecular species through advanced mass spectrometry techniques (Zhao et al., 2014). Lipid metabolism alterations are associated with various disease states, such as atherosclerosis, obesity, and diabetes. Lipid profiling, a specialized subset of lipidomics, is a well-known component of cardiovascular care for numerous clinicians and entails the measurement of low-density lipoproteins (LDL) and apolipoprotein-B (ApoB)-containing lipoproteins. Targeted lipid profiling is utilized by clinicians and researchers to evaluate cardiovascular risk and guide interventions (14, 15). Figure 1 represents the workflow of metabolomics.

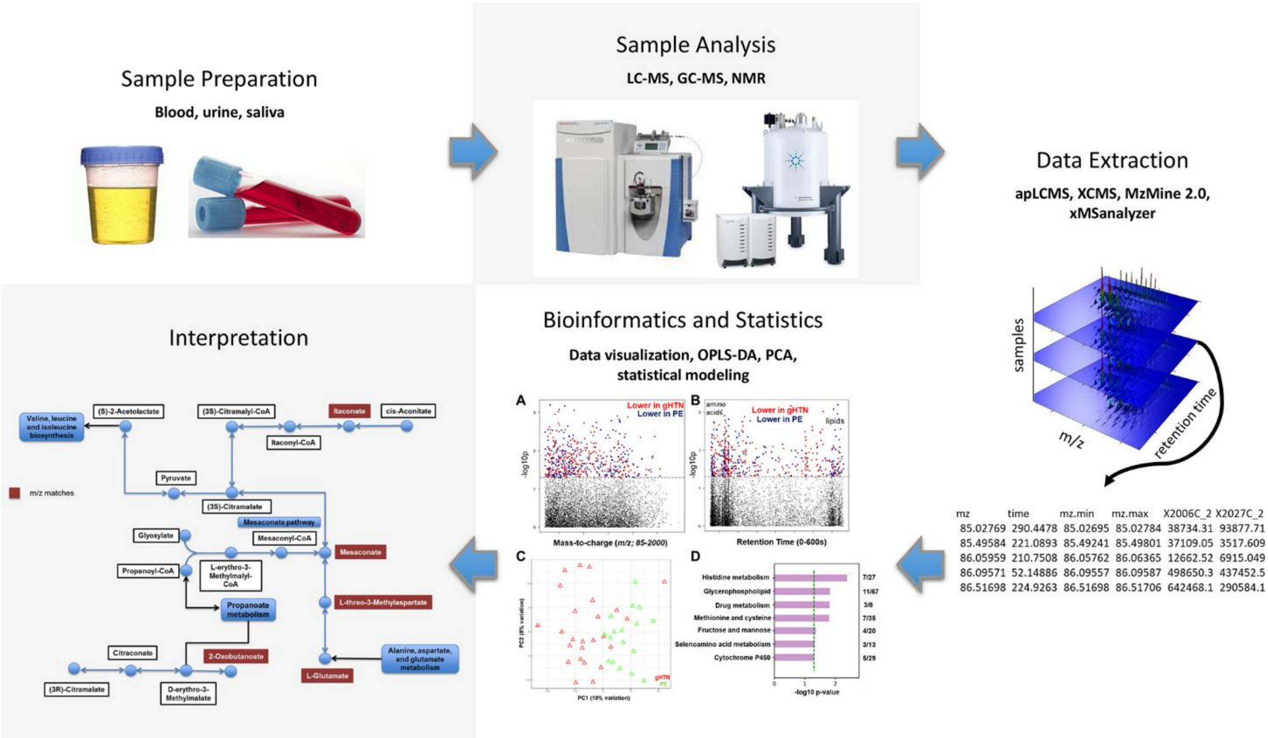

Figure 1. Workflow for Metabolomics (15).

4. Metabolomic Approaches: A Comparison of Untargeted and Targeted Methods

Metabolomics encompasses two main methodologies: untargeted and targeted analyses (6). Untargeted metabolomics represents a comprehensive approach in which researchers formulate hypotheses by analyzing the relationships between metabolites and/or metabolic pathways and particular disease conditions (6). Untargeted metabolomics is characterized by the lack of a predetermined target, as researchers do not concentrate on a specific list or class of metabolites linked to the disease under investigation. Untargeted metabolomics quantifies all known and unknown metabolites in a sample, facilitating the discovery of previously unrecognized disease mechanisms or environmental exposures (16). This method enables the detection of thousands of individual metabolites in one analysis, offering a thorough perspective on the metabolic response to different clinical conditions or interventions. However, it may provide limited information about the exact structural identity of distinguishing metabolites, necessitating follow-up experiments to confirm the identities of metabolites considered significant to the outcomes in question.

5. Targeted metabolomics

Targeted metabolomics, on the other hand, concentrates on a specific set of metabolites that are directly associated with a particular disease or condition (6). This strategy enables researchers to minimize the number of individual assays required while facilitating the accurate quantification of multiple metabolites concurrently. Targeted approaches facilitate the investigation of specific metabolic pathways or processes. In contrast to untargeted analyses that mainly characterize the relative abundance of metabolites among samples, targeted metabolomics precisely quantifies specific metabolites in each sample through a series of experiments. The study can be approached in two manners: a hypothesis-driven method, concentrating on specific metabolites, and a hypothesis-generating method, where the focus may adapt according to initial results (17).

6. Metabolomics Procedure

Researchers, whether employing an untargeted or targeted approach, typically follow a metabolomics workflow comprising several essential stages: sample preparation, sample analysis, data extraction, bioinformatics and statistics, and interpretation (15). The analysis method generally employs mass spectrometry (MS) or nuclear magnetic resonance (NMR) spectroscopy, both of which are effective techniques for the identification and quantification of metabolites. Prior to analysis, researchers typically utilize liquid chromatography (LC) or gas chromatography (GC) to separate metabolites, facilitating improved resolution and clearer outcomes (18). Various chromatographic techniques can selectively identify different classes of metabolites based on the specific needs of the study.

7. Discussion

This scoping review analyzes the development of metabolomics research conducted by nurse scientists over the last thirty years. Although certain nurse authors led these studies, numerous others made substantial contributions as team members. Our findings correspond with wider trends in metabolomics research (19), demonstrating that the majority of studies were carried out in the United States and published across various biological journals. The increase in nurse scientists publishing metabolomics research is noteworthy; however, they continue to constitute a minor segment of the broader scientific community involved in this area. Metabolomics offers significant potential for investigating the mechanisms associated with various clinical conditions, supporting diverse research objectives, including hypothesis development and testing. Considering the present and expected future effects of metabolomics on patient outcomes, nurse scientists need to engage actively in this emerging research field. This review indicates that nurse scientists contributed to metabolomics research and led research teams in 40% of the identified studies. Their focus on patient-centered research enables effective utilization of metabolomics, directing studies that produce clinically relevant outcomes for high-quality, precision interventions.

The review indicates that nurse scientists currently demonstrate a broader but shallower engagement with metabolomics. This is comprehensible, given that the field of metabolomics is relatively nascent, and nursing's involvement with these methodologies commenced approximately a decade ago (20). The most comprehensive metabolomics research program identified in this review was conducted by Wang and colleagues, concentrating on heart failure patients (21, 22), despite the absence of nurse scientists in leading these studies. Enhancing the emphasis on omics science in nursing doctoral programs may prompt nurse scientists to integrate metabolomics methodologies earlier in their academic and research trajectories, which could result in more integrated and developed research initiatives in metabolomics over the next 5–10 years (23).

The majority of studies examined were mainly hypothesis-generating rather than hypothesis-testing, frequently employing samples gathered for alternative biomarker evaluations. Consequently, these samples may not have complied with the stringent specimen collection protocols required for rigorous metabolomics analyses (24). Utilizing existing specimens for secondary analyses is efficient; however, research reliant on available data does not possess the rigor found in studies that employ prospective specimen collection aimed at testing specific hypotheses. In the upcoming decade, it is anticipated that nurse scientists will direct their research efforts toward hypothesis-testing studies that incorporate the prospective collection of metabolomics data, including healthy control groups and validation samples to support their findings (25).

8. Constraints

This scoping review presents multiple limitations. Our emphasis on literature from established databases resulted in the exclusion of gray literature. Although additional metabolomics studies by nurse scientists may exist in the gray literature, our focus is on those published in peer-reviewed journals. Furthermore, not all pertinent studies were likely included in this review. Our attempts to identify nurse authors through database and manual searches have been largely hindered, as most databases do not permit queries based on the professional backgrounds of authors. As a result, our search strategy, which focused on nurse scientists associated with nursing schools, may have missed individuals in other disciplines. This review does not offer a thorough evaluation of the quality of the studies included. Although assessing methodological quality is generally not a prerequisite in scoping reviews, its inclusion would have been advantageous (26). The metabolomics field is characterized by an absence of a standardized framework for evaluating study rigor, resulting in significant variability in methodologies across nursing science and other disciplines (27, 28).

9. Consequences for Nursing

Metabolomics is an emerging methodology that allows researchers to investigate the physiological mechanisms associated with human diseases in depth. Nurse scientists need to incorporate metabolomics techniques to improve care for individuals encountering diverse health challenges. The National Institutes of Health, including the National Institute of Nursing Research, has historically supported metabolomics and related omics research. This domain necessitates collaboration among clinical scientists, molecular chemists, and bioinformatics specialists. Innovation frequently arises at the convergence of traditionally isolated disciplines, promoting swift scientific progress (15).

The integration of metabolomics research poses considerable challenges for nurse scientists, especially in the realm of data analysis (16). Nurse scientists should demonstrate proficiency in advanced statistical programming languages such as R or Python, possess data management capabilities, and be trained in statistical analysis techniques, including basic inference, study design, and machine learning. Nurse scientists can strengthen their leadership or collaborative roles in multidisciplinary omics projects by acquiring expertise in contemporary analytical methods (29). Additionally, educational programs designed for nursing students should include curricula that emphasize the biochemical mechanisms of disease, enabling students to analyze the relevance of specific metabolites or metabolic pathways in different disease conditions.

Student nurse scientists must comprehend the engagement with basic sciences and laboratory facilities to align their research effectively with institutional resources. This involves acquiring the necessary resources for the collection, processing, and storage of biological samples by established metabolomics protocols (7). Collaborations with bioinformatics companies, such as Metabolon (www.metabolon.com), provide significant advantages for nurse scientists who do not have in-house bioinformatics support, facilitating high-throughput sample analysis and aiding in data interpretation.

10. Future Directions

A concerted effort is necessary to integrate metabolomics into nursing research. This involves promoting collaborative projects that integrate diverse skill sets and expertise across multiple disciplines. Nurse scientists can enhance the depth and quality of their research, resulting in impactful findings that improve patient outcomes. Nursing education programs must integrate training in metabolomics and related disciplines to ensure that future nurse scientists possess comprehensive knowledge of both theoretical and practical dimensions of this field.

Establishing research networks or partnerships between nursing schools and research institutes can enhance access to resources such as biorepositories, advanced analytical technologies, and statistical support. Nurse scientists ought to advocate for funding opportunities specifically designed for metabolomics research to secure essential grants for advancing their projects.

Future metabolomics research conducted by nurse scientists should prioritize the examination of health disparities by analyzing variations in metabolic profiles among diverse populations and disease states. This may yield essential insights into personalized care strategies, resulting in more effective interventions. Nurse scientists must publish their findings in high-impact journals related to metabolomics and healthcare literature, thereby enhancing the body of knowledge that highlights nursing contributions to this innovative field.

11. Conclusion

Metabolomics is evolving as a significant area of scientific exploration, presenting nurse scientists with an opportunity to enhance their research capabilities. Integrating metabolomics methods and fostering interdisciplinary collaborations can significantly enhance the understanding of human health and disease. This integration will facilitate more tailored and effective healthcare solutions, enhancing the role of nursing science in managing the complexities of patient care within a dynamic health landscape. The nursing profession can significantly enhance its influence in the metabolomics field through commitment and innovation, thereby improving health outcomes for various populations.

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العنوان: تبعات البحث البيوكيميائي على تعليم التمريض: مراجعة

المُلخَّص

الخلفية :يعدُّ دراسة التغيرات الأيضية في الأنظمة البيولوجية، أو الـ "ميتابولوميكس"، موضوعًا جديدًا يُسلط الضوء على أسباب الأمراض وتأثيراتها على الصحة. تقتضي تطورات علم التمريض دمج الـ "ميتابولوميكس" في الأبحاث لتحسين رعاية المرضى من خلال التدخلات الشخصية.

الطريقة :تتناول هذه المراجعة الشاملة أبحاث الـ "ميتابولوميكس" التي أُجريَت من قِبل علماء التمريض على مدار الثلاثة عقود الماضية. تُبرز هذه المراجعة التطورات في أساليب الـ "ميتابولوميكس"، بما في ذلك الأساليب غير المستهدفة والمستهدفة، بينما تحلل أيضًا مساهمات الباحثين الممرضين في هذا المجال.

النتائج :على الرغم من أنهم يشكلون نسبة صغيرة من المجتمع العلمي الأكبر، تُظهر المراجعة أن علماء التمريض يزداد تفاعلهم مع أبحاث الـ "ميتابولوميكس". تشير النتائج الأساسية إلى أن الغالبية العظمى من الدراسات تَوَلّد فرضيات وتعتمد على عينات موجودة بدلاً من تجميع العينات بشكل استباقي، مما قد يقيد دقتها.

الخاتمة :يجب أن تدعم الأبحاث المستقبلية الشراكات متعددة التخصصات، وتحسن المناهج التعليمية لتشمل تدريبًا على الـ "ميتابولوميكس"، وتعطي الأولوية للدراسات التي تختبر الفرضيات من أجل تحقيق الإمكانات الكاملة للـ "ميتابولوميكس" في التمريض. يمكن لعلماء التمريض تعزيز الفهم للاستجابات الأيضية عبر مجموعة متنوعة من حالات الصحة، مما يؤدي إلى تحسين النتائج الصحية للمرضى.

الكلمات المفتاحية :الطب الشخصي، الميتابولوميكس، علم التمريض، اختبار الفرضيات، التعاون متعدد التخصصات.