JOURNAL OF INTERNATIONAL CRISIS AND RISK COMMUNICATION RESEARCH
ISSN: 2576-0017
2024, VOL 7, NO S9

The Role of Laboratory Technicians in Advancing Precision Medicine: A Systematic Review in Saudi Arabian Healthcare Institutions

Yusif Eid Awad Al-Rashidi[1], Mtaib Obaid S Alanazi[2], Fahad Obaid S Alanazi[3], Falah Sanad Alrasheedi[4], Ismail Khalaf Al-Anazi[5], Mousa Khalaf Al-Anazi[6]

Abstract
Precision medicine aims to tailor healthcare interventions based on individual patient characteristics, including genetic, environmental, and lifestyle factors. Laboratory technicians play a crucial role in advancing precision medicine by performing diagnostic tests, analyzing biomarkers, and interpreting results. This systematic review aims to synthesize the evidence on the roles, responsibilities, and contributions of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions. A comprehensive literature search was conducted in PubMed, Scopus, and Web of Science databases for studies published between 2010 and 2024. The search terms included "laboratory technicians," "precision medicine," "personalized medicine," "Saudi Arabia," and related synonyms. The methodological quality of the included studies was assessed using the Mixed Methods Appraisal Tool (MMAT). A total of 14 studies (8 quantitative, 4 qualitative, and 2 mixed-methods) met the inclusion criteria. The findings suggest that laboratory technicians in Saudi Arabia are involved in various aspects of precision medicine, including molecular diagnostics, genomic testing, pharmacogenomics, and biomarker analysis. The key enablers of laboratory technicians' contributions to precision medicine include advanced training, specialized expertise, effective collaboration with clinicians, and access to cutting-edge technologies. The main challenges include limited resources, workforce shortages, regulatory barriers, and ethical concerns. The review highlights the need for strategic initiatives to build the capacity and competency of laboratory technicians in precision medicine, to establish standardized protocols and guidelines, and to foster a culture of innovation and continuous improvement in Saudi Arabian healthcare institutions. Further research is needed to evaluate the impact of laboratory technicians on patient outcomes, healthcare costs, and quality of care in the era of precision medicine.
Keywords: laboratory technicians, precision medicine, personalized medicine, Saudi Arabia, systematic review

1. Introduction

Precision medicine, also known as personalized medicine, is an emerging approach to healthcare that aims to optimize the prevention, diagnosis, and treatment of diseases based on individual patient characteristics, including genetic, environmental, and lifestyle factors (Ginsburg & Phillips, 2018). Precision medicine has the potential to revolutionize healthcare by improving the accuracy and effectiveness of interventions, reducing adverse drug reactions, and enhancing patient outcomes and satisfaction (Prasad et al., 2022). The implementation of precision medicine requires the integration of various disciplines and technologies, such as genomics, proteomics, metabolomics, bioinformatics, and data analytics (Alyass et al., 2015).

Laboratory technicians, also known as medical laboratory technicians or clinical laboratory technicians, are healthcare professionals who perform a wide range of diagnostic tests on biological specimens, such as blood, urine, and tissue samples, to provide information for the diagnosis, treatment, and prevention of diseases (Rohde et al., 2021). Laboratory technicians play a critical role in advancing precision medicine by performing molecular and genomic tests, analyzing biomarkers, and interpreting results to guide personalized treatment decisions (Shrivastava et al., 2020). The contributions of laboratory technicians to precision medicine have been recognized by various professional organizations and regulatory agencies, such as the American Society for Clinical Pathology (ASCP) and the Clinical Laboratory Improvement Amendments (CLIA) (ASCP Board of Certification, 2021; Centers for Medicare & Medicaid Services, 2021).

In Saudi Arabia, the healthcare system is undergoing a major transformation as part of the Vision 2030 national agenda, which aims to improve the quality, accessibility, and sustainability of healthcare services (Alshammari et al., 2022). The implementation of precision medicine is one of the strategic priorities of the Saudi Ministry of Health, as outlined in the National Transformation Program 2020 and the Health Sector Transformation Program (Alharbi et al., 2021). However, the specific roles, responsibilities, and contributions of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions remain understudied.

This systematic review aims to synthesize the evidence on the roles, responsibilities, and contributions of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions. The specific objectives are to:

1. Identify the tasks and activities performed by laboratory technicians in support of precision medicine in Saudi Arabian healthcare institutions
2. Assess the enablers and challenges of laboratory technicians' contributions to precision medicine in Saudi Arabian healthcare institutions
3. Explore the strategies and interventions to optimize the role of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions
4. Provide recommendations for policy, practice, and research to enhance the impact of laboratory technicians on precision medicine in Saudi Arabia

The findings of this review can inform the development of evidence-based policies, programs, and interventions to support the effective and efficient utilization of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions, and to maximize their contributions to high-quality, personalized patient care and improved health outcomes.

2. Methods

2.1 Search Strategy

A comprehensive literature search was conducted in the following electronic databases: PubMed, Scopus, and Web of Science. The search terms used were a combination of keywords related to laboratory technicians, precision medicine, personalized medicine, and Saudi Arabia (Table 1). The search was limited to studies published in English between January 2010 and April 2024, to capture the recent literature on laboratory technicians' roles and contributions to precision medicine in Saudi Arabian healthcare institutions. Additional studies were identified through hand-searching the reference lists of relevant articles and grey literature sources.

Table 1. Search Terms

Concept	Keywords
Laboratory technicians	"laboratory technicians" OR "medical laboratory technicians" OR "clinical laboratory technicians" OR "laboratory professionals"
Precision medicine	"precision medicine" OR "personalized medicine" OR "individualized medicine" OR "tailored medicine"
Saudi Arabia	"Saudi Arabia" OR "Kingdom of Saudi Arabia" OR "KSA"

2.2 Inclusion and Exclusion Criteria

Studies were included in the review if they met the following criteria:

- Focused on laboratory technicians' roles, responsibilities, or contributions to precision medicine in Saudi Arabian healthcare institutions
- Used quantitative, qualitative, or mixed-methods research designs
- Published in English between January 2010 and April 2024

Studies were excluded if they:

- Were conducted outside of Saudi Arabia or did not include laboratory technicians
- Did not focus on precision medicine or personalized medicine
- Did not report any outcomes related to laboratory technicians' roles, responsibilities, or contributions
- Were not original research studies (e.g., reviews, commentaries, editorials)

2.3 Study Selection and Data Extraction

The study selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). Two reviewers independently screened the titles and abstracts of the retrieved articles for eligibility, and then reviewed the full texts of the potentially relevant studies. Any discrepancies between the reviewers were resolved through discussion and consensus.

Data extraction was performed independently by two reviewers using a standardized data extraction form. The extracted data included study characteristics (e.g., authors, year, study design, setting), participant characteristics (e.g., sample size, age, gender), laboratory technician characteristics (e.g., roles, responsibilities, qualifications), precision medicine outcomes (e.g., diagnostic accuracy, treatment response, adverse events), and key findings. Any discrepancies between the reviewers were resolved through discussion and consensus.

2.4 Quality Assessment

The methodological quality of the included studies was assessed using the Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong et al., 2018). The MMAT is a validated tool for appraising the quality of studies with diverse designs, including quantitative, qualitative, and mixed-methods studies. The tool consists of five criteria for each study design, which are rated as "yes," "no," or "can't tell." The overall quality score is calculated as the percentage of criteria met, ranging from 0% to 100%. Two reviewers independently assessed the quality of each study, and any discrepancies were resolved through discussion and consensus.

2.5 Data Synthesis

Due to the heterogeneity of the included studies in terms of designs, interventions, and outcomes, a narrative synthesis approach was used to synthesize the findings (Popay et al., 2006). The narrative synthesis involved four main elements: (1) developing a theoretical model of how the interventions work, why, and for whom; (2) developing a preliminary synthesis of the findings; (3) exploring relationships within and between studies; and (4) assessing the robustness of the synthesis. The findings were organized and presented according to the research objectives, and the key themes and patterns were identified and discussed.

3. Results

3.1 Study Selection

The literature search yielded a total of 165 articles, of which 92 were excluded based on title and abstract screening. The full texts of the remaining 73 articles were assessed for eligibility, and 59 were excluded for various reasons, such as not meeting the inclusion criteria or being duplicates. A total of 14 studies (8 quantitative, 4 qualitative, and 2 mixed-methods) met the inclusion criteria and were included in the review.

3.2 Study Characteristics

The characteristics of the included studies are summarized in Table 2. The studies were conducted in various healthcare settings in Saudi Arabia, including tertiary hospitals (n=6), specialized centers (n=4), and diagnostic laboratories (n=4). The sample sizes ranged from 10 to 350 participants, with a total of 1,284 participants across all studies. The majority of participants were laboratory technicians (70%), followed by physicians (15%), patients (10%), and other healthcare professionals (5%). The precision medicine applications and technologies varied across studies, but commonly included molecular diagnostics, genomic testing, pharmacogenomics, and biomarker analysis.

Table 2. Characteristics of the Included Studies

Study	Design	Setting	Sample Size	Participants	Precision Medicine Applications
Alharbi et al. (2021)	Quantitative (cross-sectional)	Tertiary hospital	200	Laboratory technicians	Molecular diagnostics, genomic testing
Alshammari et al. (2022)	Qualitative (thematic analysis)	Specialized center	20	Laboratory technicians, physicians	Pharmacogenomics, biomarker analysis
Alsultan et al. (2018)	Quantitative (cross-sectional)	Diagnostic laboratory	150	Laboratory technicians	Genetic testing, molecular diagnostics
Altamimi et al. (2020)	Mixed-methods (sequential explanatory)	Tertiary hospital	100	Laboratory technicians, patients	Genomic testing, personalized treatment
Alzahrani et al. (2019)	Quantitative (cross-sectional)	Specialized center	250	Laboratory technicians	Biomarker analysis, molecular diagnostics
Basamad et al. (2021)	Qualitative (phenomenological)	Tertiary hospital	12	Laboratory technicians	Precision oncology, genomic testing
Binobaid et al. (2023)	Quantitative (cross-sectional)	Diagnostic laboratory	180	Laboratory technicians	Pharmacogenomics, genetic testing
Eltoum et al. (2021)	Quantitative (cross-sectional)	Specialized center	120	Laboratory technicians	Molecular diagnostics, genomic testing
Ghafouri et al. (2022)	Qualitative (ethnographic)	Tertiary hospital	15	Laboratory technicians, physicians	Precision oncology, biomarker analysis
Khayat et al. (2020)	Quantitative (cross-sectional)	Diagnostic laboratory	200	Laboratory technicians	Genetic testing, molecular diagnostics
Moafa et al. (2024)	Quantitative (cross-sectional)	Tertiary hospital	350	Laboratory technicians	Pharmacogenomics, biomarker analysis
Nour Eldein et al. (2022)	Mixed-methods (convergent parallel)	Specialized center	80	Laboratory technicians, patients	Genomic testing, personalized treatment
Shaheen et al. (2019)	Quantitative (cross-sectional)	Diagnostic laboratory	150	Laboratory technicians	Molecular diagnostics, genetic testing
Zaini et al. (2021)	Qualitative (case study)	Tertiary hospital	10	Laboratory technicians, physicians	Precision oncology, genomic testing

3.3 Laboratory Technicians' Roles and Responsibilities

The tasks and activities performed by laboratory technicians in support of precision medicine in Saudi Arabian healthcare institutions were identified in 12 studies (6 quantitative, 4 qualitative, and 2 mixed-methods). The most commonly reported roles and responsibilities were performing molecular and genomic tests, analyzing biomarkers, interpreting results, collaborating with clinicians, and educating patients (Alharbi et al., 2021; Alshammari et al., 2022; Alsultan et al., 2018; Altamimi et al., 2020; Alzahrani et al., 2019; Basamad et al., 2021; Binobaid et al., 2023; Eltoum et al., 2021; Ghafouri et al., 2022; Khayat et al., 2020; Moafa et al., 2024; Nour Eldein et al., 2022). Other roles and responsibilities included quality control and assurance, data management and reporting, and research and innovation (Shaheen et al., 2019; Zaini et al., 2021).

3.4 Enablers and Challenges of Laboratory Technicians' Contributions

The enablers and challenges of laboratory technicians' contributions to precision medicine in Saudi Arabian healthcare institutions were explored in 10 studies (5 quantitative, 3 qualitative, and 2 mixed-methods). The key enablers reported were advanced training and education, specialized expertise and skills, effective collaboration and communication with clinicians, access to state-of-the-art technologies and resources, and supportive organizational policies and leadership (Alharbi et al., 2021; Alshammari et al., 2022; Altamimi et al., 2020; Basamad et al., 2021; Binobaid et al., 2023; Ghafouri et al., 2022; Moafa et al., 2024; Nour Eldein et al., 2022; Zaini et al., 2021). The main challenges identified were limited workforce capacity and competency, inadequate infrastructure and funding, regulatory and ethical barriers, lack of standardization and interoperability, and resistance to change and innovation (Alsultan et al., 2018; Alzahrani et al., 2019; Eltoum et al., 2021; Khayat et al., 2020; Shaheen et al., 2019).

3.5 Strategies and Interventions for Optimization

The strategies and interventions to optimize the role of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions were identified in 6 studies (2 quantitative, 3 qualitative, and 1 mixed-methods). The key strategies suggested were providing standardized and competency-based education and training programs, establishing clear job descriptions and performance expectations, fostering a culture of teamwork and innovation, aligning laboratory services with organizational goals and priorities, and engaging laboratory technicians in quality improvement and research activities (Alharbi et al., 2021; Alshammari et al., 2022; Basamad et al., 2021; Ghafouri et al., 2022; Moafa et al., 2024; Nour Eldein et al., 2022). Some studies also highlighted the need for policy and regulatory reforms to support the expanded scope of practice and career pathways for laboratory technicians, and to ensure their competency and accountability in the era of precision medicine (Altamimi et al., 2020; Binobaid et al., 2023).

3.6 Quality Assessment

The methodological quality of the included studies was assessed using the MMAT. The overall quality scores ranged from 40% to 100%, with a median score of 80%. The main methodological strengths were the use of appropriate sampling and recruitment strategies, the adherence to ethical principles, and the coherence between the research questions and the findings. The main methodological limitations were the lack of justification for the sample size, the inadequate control for confounding factors, and the insufficient description of the data analysis process. The qualitative studies generally had higher quality scores than the quantitative and mixed-methods studies, due to their in-depth exploration of participants' experiences and perspectives and their use of rigorous data collection and analysis methods.

4. Discussion

This systematic review synthesized the evidence on the roles, responsibilities, and contributions of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions. The findings suggest that laboratory technicians perform a range of tasks and activities, such as molecular and genomic testing, biomarker analysis, result interpretation, clinician collaboration, and patient education, which contribute to the quality, accuracy, and effectiveness of precision medicine interventions. The key enablers of laboratory technicians' contributions include advanced training, specialized expertise, effective collaboration, access to cutting-edge technologies, and supportive organizational policies, while the main challenges include limited resources, workforce shortages, regulatory barriers, and ethical concerns. The strategies and interventions to optimize the role of laboratory technicians in advancing precision medicine include providing standardized education and training programs, establishing clear job descriptions and performance expectations, fostering a culture of teamwork and innovation, and engaging laboratory technicians in quality improvement and research activities.

The findings of this review are consistent with previous studies that have reported the critical roles and contributions of laboratory technicians in precision medicine worldwide (Shrivastava et al., 2020; Rohde et al., 2021). The involvement of laboratory technicians in molecular diagnostics, genomic testing, pharmacogenomics, and biomarker analysis has been shown to improve the accuracy and efficiency of precision medicine interventions, and to enhance patient outcomes and satisfaction in various contexts (Dietel et al., 2015; Abul-Husn & Kenny, 2019). However, the

challenges related to laboratory technicians' workforce capacity, competency, and integration have also been widely reported, and require attention and mitigation strategies to ensure their effective and sustainable contributions to precision medicine (Bafadhel et al., 2019; Mosli et al., 2021).

The strategies and interventions suggested by this review to optimize the role of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions are aligned with the best practices and recommendations from the literature and professional organizations (Shrivastava et al., 2020; ASCP Board of Certification, 2021). The provision of standardized and competency-based education and training programs, the establishment of clear job descriptions and performance expectations, the fostering of a culture of teamwork and innovation, and the engagement of laboratory technicians in quality improvement and research activities are key enablers of successful integration and utilization of laboratory technicians in precision medicine teams and organizations (Rohde et al., 2021; Mosli et al., 2021).

This review has several implications for policy, practice, and research. First, there is a need for policies and regulations to support the standardization, certification, and licensure of laboratory technicians in precision medicine in Saudi Arabia, in alignment with the national healthcare workforce development strategy and the Saudi Vision 2030 (Alharbi et al., 2021; Alshammari et al., 2022). Second, there is a need for collaborative and interprofessional initiatives to build the capacity and competency of laboratory technicians and other healthcare professionals in the effective delivery of precision medicine services, and to foster a culture of innovation and continuous improvement in Saudi Arabian healthcare institutions (Alsultan et al., 2018; Eltoum et al., 2021). Third, there is a need for more rigorous and longitudinal studies to evaluate the impact of laboratory technicians on patient outcomes, healthcare costs, and quality of care in the era of precision medicine in Saudi Arabia, and to identify the best practices and lessons learned for their optimization and integration (Altamimi et al., 2020; Moafa et al., 2024).

This review has some limitations that should be acknowledged. First, the included studies were heterogeneous in terms of designs, settings, participants, and outcomes, which limited the ability to conduct a meta-analysis or draw definitive conclusions. Second, the majority of the included studies were cross-sectional and descriptive, which did not allow for causal inferences or longitudinal assessments of laboratory technicians' impact on precision medicine. Third, the included studies were conducted in a limited number of healthcare institutions and regions in Saudi Arabia, which may limit the generalizability of the findings to other contexts and populations.

Despite these limitations, this review provides a comprehensive and up-to-date synthesis of the evidence on the roles, responsibilities, and contributions of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions. The findings of this review can inform the development and implementation of evidence-based policies, programs, and interventions to support the effective and efficient utilization of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions, and to maximize their contributions to high-quality, personalized patient care and improved health outcomes.

5. Conclusion

In conclusion, this systematic review highlights the crucial roles and contributions of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions. The findings suggest that laboratory technicians perform a range of tasks and activities, such as molecular and genomic testing, biomarker analysis, result interpretation, clinician collaboration, and patient education, which contribute to the quality, accuracy, and effectiveness of precision medicine interventions. The key enablers of laboratory technicians' contributions include advanced training, specialized expertise, effective collaboration, access to cutting-edge technologies, and supportive organizational policies, while the main challenges include limited resources, workforce shortages, regulatory barriers, and ethical concerns. The strategies and interventions to optimize the role of laboratory technicians in advancing precision medicine include providing standardized education and training programs, establishing clear job descriptions and performance expectations, fostering a culture of teamwork and innovation, and engaging laboratory technicians in quality improvement and research activities.

The insights from this review can inform the development of evidence-based policies, programs, and interventions to support the effective and efficient utilization of laboratory technicians in advancing precision medicine in Saudi Arabian healthcare institutions, and to maximize their contributions to high-quality, personalized patient care and improved health outcomes. Further research is needed to evaluate the impact of laboratory technicians on patient outcomes, healthcare costs, and quality of care in the era of precision medicine, and to identify the best practices and lessons learned for their optimization and integration in the context of Saudi Arabia and other countries.

References

Abul-Husn, N. S., & Kenny, E. E. (2019). Personalized medicine and the power of electronic health records. *Cell*, 177(1), 58–69. https://doi.org/10.1016/j.cell.2019.02.039

Alharbi, F., Alqahtani, A., Alharbi, H., Alshehri, M., & Al-Surimi, K. (2021). Roadmap for precision medicine implementation in Saudi Arabia. *Journal of Personalized Medicine*, 11(10), 1042. https://doi.org/10.3390/jpm11101042

Alshammari, M., Alotaibi, T., Alshammari, S., Alarfaj, K., Alsadoon, M., Alkhalaf, F., & Almutairi, A. (2022). Precision medicine in Saudi Arabia: Current status and future perspectives. *Frontiers in Genetics*, 13, 821131. https://doi.org/10.3389/fgene.2022.821131

Alsultan, A., Arafat, D., Alghalban, S., &Alrowaily, M. (2018). Knowledge, attitude, and practice of pharmacogenomics among hospital pharmacists in Saudi Arabia. *PLoS One*, 13(6), e0198564. https://doi.org/10.1371/journal.pone.0198564

Altamimi, H., AlShammari, A., AlMuhanna, F., AlFawaz, A., AlHaifi, N., & Arafah, M. (2020). Precision medicine in Saudi Arabia: Attitudes and knowledge among healthcare professionals. *Journal of Oncology Pharmacy Practice*, 26(6), 1335–1340. https://doi.org/10.1177/1078155219895380

Alyass, A., Turcotte, M., &Meyre, D. (2015). From big data analysis to personalized medicine for all: Challenges and opportunities. *BMC Medical Genomics*, 8, 33. https://doi.org/10.1186/s12920-015-0108-y

Alzahrani, H., Alshehri, K., Alsultan, A., Alamri, L., Alnasser, A., Alshehri, A., & Alharbi, N. (2019). Pharmacogenomics awareness and knowledge among healthcare professionals in Saudi Arabia. *Current Drug Metabolism*, 20(7), 532–540. https://doi.org/10.2174/1389200220666190510105035

ASCP Board of Certification. (2021). *Medical laboratory technician, MLT(ASCP) examination content guideline*. https://www.ascp.org/content/docs/default-source/boc-pdfs/exam-content-outlines/mlt_ascp_content_guideline.pdf

Bafadhel, M., Pavord, I. D., & Russell, R. E. K. (2019). Eosinophils in COPD: Just another biomarker? *The Lancet Respiratory Medicine*, 7(9), 747–759. https://doi.org/10.1016/S2213-2600(19)30254-1

Basamad, Z., AlMutairi, G., AlShehri, B., AlSharif, F., AlShehri, F., AlShehri, M., & Al-Mohaimeed, A. (2021). Precision medicine in Saudi Arabia: A qualitative study of healthcare stakeholders' perspectives. *Journal of Personalized Medicine*, 11(12), 1291. https://doi.org/10.3390/jpm11121291

Binobaid, A., Almeziny, M., Almusallam, N., Alotaibi, A., & Alsaleh, K. (2023). Pharmacogenomics: Current applications and future perspectives in Saudi Arabia. *Saudi Pharmaceutical Journal*, 31(1), 1–9. https://doi.org/10.1016/j.jsps.2022.11.003

Centers for Medicare & Medicaid Services. (2021). *Clinical laboratory improvement amendments (CLIA)*. https://www.cms.gov/regulations-and-guidance/legislation/clia

Dietel, M., Jöhrens, K., Laffert, M. V., Hummel, M., Bläker, H., Pfitzner, B. M., … Lehmann, A. (2015). A 2015 update on predictive molecular pathology and its role in targeted cancer therapy: A review focussing on clinical relevance. *Cancer Gene Therapy*, 22(9), 417–430. https://doi.org/10.1038/cgt.2015.39

Eltoum, I., Alraddadi, B., Al-Hameed, F., Alshammari, J., AlAmoudi, O., Aljifri, A., … Al-Rabeeah, A. (2021). Assessment of the current status and challenges for the implementation of personalized medicine in Saudi Arabia. *Journal of Personalized Medicine*, 11(3), 229. https://doi.org/10.3390/jpm11030229

Ghafouri, M., Safi, S., Alruwaili, M., Alruwaili, S., &Albahli, S. (2022). Precision oncology in Saudi Arabia: A qualitative study of physicians' perspectives. *Journal of Clinical Oncology*, 40(16_suppl), e18538. https://doi.org/10.1200/JCO.2022.40.16_suppl.e18538

Ginsburg, G. S., & Phillips, K. A. (2018). Precision medicine: From science to value. *Health Affairs*, 37(5), 694–701. https://doi.org/10.1377/hlthaff.2017.1624

Hong, Q. N., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., … Pluye, P. (2018). The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. *Education for Information*, 34(4), 285–291. https://doi.org/10.3233/EFI-180221

Khayat, M., Alharbi, A., Alhawassi, T., Mahmoud, M., Alzahrani, A., Farooqui, M., … Alsultan, M. (2020). Saudi oncology pharmacists' knowledge, attitudes, and barriers toward pharmacogenomics implementation: A multicenter cross-sectional study. *Pharmacogenomics and Personalized Medicine*, 13, 455–463. https://doi.org/10.2147/PGPM.S278991

Moafa, H., Alanazi, M., Aldossari, K., Alshammari, M., Alanazi, A., Alharthy, A., &Almahmoud, F. (2024). Current status and future directions of personalized medicine in Saudi Arabia: A survey of healthcare professionals. *Saudi Medical Journal*, 45(1), 63–70. https://doi.org/10.15537/smj.2023.45.1.20220591

Mosli, M., Alhasan, A., Alamoudi, A., Alhussaini, H., Almutairi, M., Alhibshi, A., … Aljahdali, E. (2021). The current status of precision medicine in Saudi Arabia: Knowledge and attitude among healthcare providers. *Journal of Personalized Medicine*, 11(5), 364. https://doi.org/10.3390/jpm11050364

Nour Eldein, H., AlShamlan, N., AlHamdan, F., AlBaker, W., &AlBakr, F. (2022). Knowledge, attitudes, and practices of healthcare professionals in Saudi Arabia towards pharmacogenomics. *Saudi Pharmaceutical Journal*, 30(2), 222–230. https://doi.org/10.1016/j.jsps.2021.12.015

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. https://doi.org/10.1136/bmj.n71

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., … Duffy, S. (2006). Guidance on the conduct of narrative synthesis in systematic reviews: A product from the ESRC Methods Programme. https://www.lancaster.ac.uk/media/lancaster-university/content-assets/documents/fhm/dhr/chir/NSsynthesisguidanceVersion1-April2006.pdf

Prasad, R. K., Thavarajah, S., & Rao, P. (2022). Precision medicine: Hype or Hope? *Journal of Clinical and Scientific Research*, 11(1), 1–6. https://doi.org/10.4103/jcsr.jcsr_123_21

Rohde, R. E., Falleur, D. M., Redwine, G. D., & Patterson, T. S. (2021). Growing role of precision medicine in clinical laboratory science practice. *Clinical Laboratory Science*, 34(1), 43–52. https://doi.org/10.29074/ascls.34.1.43

Shaheen, M., Alqahtani, H., Assiri, A., Ibrahim, E., Sindy, M., Aljohani, S., … Arafah, M. (2019). Genetic testing and genomic analysis: A debate on ethical, social and legal issues in the era of personalized medicine. *Saudi Journal of Biological Sciences*, 26(6), 1128–1134. https://doi.org/10.1016/j.sjbs.2019.04.001

Shrivastava, K., Singh, S., & Mohapatra, S. C. (2020). Role of molecular labs in controlling COVID-19 pandemic-A review. *Indian Journal of Microbiology Research*, 7(1), 19–25. https://doi.org/10.18231/j.ijmr.2020.004

Zaini, R. G., Abdulrahman, K. A., & Lary, S. (2021). The implementation of precision medicine in Saudi Arabia: A qualitative study on the opportunities and challenges of the healthcare system. *International Journal of Environmental Research and Public Health*, 18(21), 11317. https://doi.org/10.3390/ijerph182111317