The Review Of
DIABETIC
STUDIES
OPEN ACCESS

The Role Of Innovative Technological Developments In Laboratory Medicine

Abrar Mohammed Hadi Ayob[1], Dalia Abdullah Ajaj[2], Zohour Matooq Alyamani[3], Fatmah Mohammad Saeed Hariri[4], Abdulrahman Khaled Zamzami[5], Adel Abdulrahman Ahmad Abonawas[6], Aayed Abdullah Yahya Al-Maliki[7], Ayman Hussien Abdulraheem[8], Hani Hassan Alfi [9], Hanno Farok Joharje[10], Alaa Saud Aloufi[11]

[1]Laboratory Specialist- Jeddah regional Laboratory
[2]Laboratory Technician- Hera General Hospital
[3]Laboratory technician- Hera general hospital
[4]Laboratory technician- Hera general hospital
[5]Laboratory Technician- Hera General Hospital
[6]Laboratory Specialist -Maternity and Children's Hospital in Makkah
[7]Laboratory specialist-Death Management at the Forensic Medical Services Center in Makkah
[8]Laboratory specialist- The Forensic Medical Services Center in Makkah
[9]Laboratory specialist- Ibn Sena Hospital for Extended Care
[10]Laboratory specialist – Al-Awali Primary Healthcare center
[11]Laboratory specialist – Al-Awali Primary Healthcare center

Abstract
Background: The medical field is developing on the technological grounds by leaps and bounds and Saudi Arabia is no exception to the same. As far as role of innovative technology in the medical laboratories is concerned, most of the urban and semi urban areas of the country have adopted the same and but still there is some lacuna in the rural areas. Then on the other hand the training and development of the respective staff for awareness and adoption of new technology is still in the stage of infancy. This present study will evaluate the scenario in the light of data collected from selected medical laboratories in Dammam and Al Khobar; the two cities of Saudi Arabia.
Study Objectives: This study's primary goal is to determine the types and prevalence of cutting-edge technologies utilized in laboratory medicine in Saudi Arabia. It also aims to determine how laboratory workers perceive the advantages and difficulties of these technologies.

a. Materials and Methods: Study is based in the urban areas of Dammam city and semi urban areas of Al Khobar. Some of the rural areas surrounding both the cities will also be included. A sample of 350 technicians, Biomedical engineers, clinical pathologists and LIS specialists was taken from the above said places. Study includes Cross sectional study design and uses Binary Logistic Regression and Chi Square test as statistical tool. SPSS ver. 27.0 will be used to analyze the data.

Keywords: Adoption of technology, Role of laboratories, technological developments.

Background

During the past few decades, the integration of automation technology has played a major role in the considerable development of the clinical laboratory operations landscape. (Wilson et al 2022) As laboratories work to improve diagnostic process accuracy and efficiency, this evolution is both a reaction to and a catalyst for shifts in healthcare expectations. Clinical labs now face new challenges as a result of the quick developments in medical sciences and the growing focus on personalized medicine. (Alghamdi et al 2022) They must manage high standards of precision and dependability while handling growing test volumes with strict turnaround times.Pre-analytical and post-analytical phases are all included in the broad range of technology and procedures that make up clinical laboratory automation.

These consist of advancements in automated analyzers for hematological and biochemical testing, robotics for handling specimens, and advanced laboratory information management systems (LIMS) for reporting and data integration. (Al-Mohaimeed et al 2021) As these technologies advance, they not only eliminate human error and streamline procedures, but they also improve the laboratory's ability

to deliver actionable insights more quickly and precisely.This research attempts to investigate the new developments in clinical laboratory automation that are changing the operational dynamics of the sector. It will explore a range of automated solution topics, including how they affect laboratory operations, cost-effectiveness, and diagnosis accuracy. (Wong et al 2020)
It will also cover the integration of internet-of-things (IoT) devices that provide real-time monitoring and quality control, as well as the role of AI and machine learning in streamlining lab operations. (Alshammari et al 2023) This work is important not only because it may demonstrate recent achievements but also because it can offer practical advice for upcoming advancements in laboratory automation.
This research aims to inform strategic choices for laboratory managers, technology developers, and healthcare regulators who are working toward a more effective and responsive healthcare delivery system by detecting important trends and projecting their effects. (Kiechle et al 2019) In order to tackle the challenges of modern medicine, it will be essential to comprehend and apply innovative automation technologies as the demand for faster throughput and more complex diagnostic capabilities keeps increasing. This introduction lays the groundwork for a thorough analysis of how clinical laboratory automation is breaking new ground in medical diagnostics and guaranteeing that labs continue to be a vital component of effective and efficient patient care. (Al-Tawfiq et al 2020)
With vital diagnostic services that support clinical judgments and aid in illness prevention, diagnosis, monitoring, and treatment, laboratories form the foundation of the healthcare system. The ambitious reforms stated in Vision 2030, which seek to improve healthcare services and infrastructure nationwide, have significantly transformed the Saudi Arabian healthcare sector. Laboratories have been essential to this change by providing rapid and accurate diagnostic data to healthcare practitioners. Modern laboratories cannot function properly without laboratory staff, including technicians and technologists. (Alqahtani et al 2022)
These experts carry out diagnostic examinations, examine samples, and guarantee the precision and dependability of test findings. Their efforts assist medical professionals in making well-informed judgments on patient care. (Lippi et al 2020) The expansion and modernization of Saudi Arabia's healthcare industry has led to a notable surge in the need for qualified laboratory workers. This essay offers a thorough analysis of the function of laboratories in Saudi Arabia, emphasizing the contributions made by lab technologists and technicians. It talks about their responsibilities, educational paths, and the difficulties they encounter at work. The article also discusses the significance of cooperation between laboratory staff and medical experts and examines developments in laboratory technology. The present status of laboratory services in Saudi Arabia is examined in this research to highlight the vital role that laboratories play in assisting the healthcare system and promoting public health.

Literature Review

Clinical laboratory automation offers enormous potential to increase diagnostic testing's throughput, accuracy, and efficiency, and it signifies a paradigm shift in the healthcare sector. (Alzahrani et al 2023) This overview of the literature provides a basis for the investigation of the transformational influence of clinical laboratory automation by summarizing the current discussion of its emerging patterns.Clinical laboratory automation began in the 1950s, mainly with the advent of automated analyzers that were intended to reduce the workload associated with manual testing procedures. (Pantanowitz et al 2020) Throughout the years, these technologies have advanced significantly, moving from basic mechanization to extremely complex systems that include artificial intelligence (AI), robots, and information systems. (Al-Mutairi et al 2021)
Automation is being driven by a number of technical breakthroughs, as highlighted in recent research. Robotics is essential for improving laboratory safety, decreasing human error, and expediting sample handling. (Topol et al 2019) By making predictive analytics, quality control, and decision support systems possible, the combination of AI and machine learning algorithms has further enhanced automation. The emergence of digital pathology, which includes tools like image analysis and entire slide imaging, is another example of how digitization is changing pathological diagnosis and workflows. Laboratory automation greatly improves productivity by boosting throughput and allowing continuous operation without the limitations of human work hours, as studies have

repeatedly shown. Automation shortens turnaround times, guaranteeing faster test result delivery—a critical component of clinical decision-making and patient care. (Alhassan et al 2022)
Furthermore, automated solutions make it easier for laboratory information systems (LIS) to integrate seamlessly, which improves interoperability and data management in healthcare networks. (Chan et al 2021) Automation has been helpful in reducing analytical errors, because accuracy and dependability are crucial in laboratory diagnosis. (Alotaibi et al 2022) The accuracy of diagnosis is increased by automated technologies, which guarantee accurate measurements and uniform sample processing. Technological advancements like computerized quality control and validation processes enhance the reliability and repeatability of lab results. Although there are advantages, there are drawbacks to implementing laboratory automation. (Ghaffar et al 2020) The necessity for constant upgrades and maintenance, complicated deployment procedures, and high initial expenses are major obstacles. Concerns about job loss and resistance to change among laboratory staff are other obstacles that must be addressed. (Alzahrani et al 2021); (Adeli et al 2020)
Additionally, concerns about data privacy and cyber-security in automated systems need to be well thought out. Clinical laboratory automation trends point to a more integrated future where breakthroughs like blockchain and the Internet of Things (IoT) may completely transform laboratory operations. (Al-Mazrou et al 2020) Advanced automation that makes quick and customized diagnostics possible is driving an increasing trend in personalized medicine, according to the literature. Maintaining interdisciplinary partnerships is essential to developing automation technologies to satisfy the growing needs of contemporary healthcare. (Alshahrani et al 2022)

Research gaps

By the way of literature review, many of the previous studies have been reviewed and the description is given above. On the basis of description some of the research gaps have been identified, the same are listed below:
- Many of the studies have not given importance to training and development of laboratory staff, provided that government had announced a policy in this regard as well.
- only a few studies have focused on the long term effect of technology adoption and economic effect of the same.
- Most of the studies have significantly mentioned the technological advancements in the urban areas, but minimum studies have focused on the impact of technological development in rural areas.

This present study will try to fill these gaps by the way of a cross-sectional study and predict the futuristic aspects related to technological advancements in the medical laboratories in Saudi Arabia.

Research Objectives

This study's primary goal is to determine the types and prevalence of cutting-edge technologies utilized in laboratory medicine in Saudi Arabia. It also aims to determine how laboratory workers perceive the advantages and difficulties of these technologies.

Research Hypothesis

Hypothesis 1

H_0: The adoption of innovative technological components in laboratory medicine is significantly associated with the improved work flow and test results of the selected laboratories in Saudi Arabia.
H_1: There is no significant association between the adoption of innovative technological components in laboratory medicine and improved work flow and test results of the selected laboratories in Saudi Arabia.

Research Methodology

Research Design

This study includes a cross-sectional descriptive research design to assess the adoption, impact and issues/challenges related to innovative technological development in laboratory medicine in Saudi Arabia. This research design allows the researcher to collect the required data at a given point of time from single set of sample units, here the sample units or the respondents of the study were laboratory professionals working in the selected medical labs in different parts of Saudi Arabia.

Study Area and Population

The researcher had considered Dammam (for urban centers) and Al khobar (For semi urban centers) for the purpose of the study and some of the rural centers (adjoining the above two cities) were also selected.

The respective population of the study will include the following:

a. Technicians engaged in the laboratories of the above mentioned cities

b. Clinical pathologists working in the selected laboratories

c. Some of the biomedical engineers working for laboratory operations

d. Some of the IT and LIS specialists working in the selected laboratories

Sampling

The researcher had implied Cochran's formula for the assessment of sample size, as this is the most suitable method to identify the sample size for a cross-sectional study. The process assumes the prevalence of technology adoption as 50% (this is the maximum possible variation). by using the above process the respective sample size reached to 362 which was rounded of to 350. Hence the final number of respondents was 350.

The the researcher has implied Stratified Random sampling method, based on the nature of laboratories (Public sector or run by private operators), location of the laboratories (Urban, Semi urban and rural).

Tool of Data Collection

Data was collected by using a detailed structured questionnaire, that will include the following parts:

- Demographic details

- Types of technologies used

- Perceived benefits

- issues and challenges

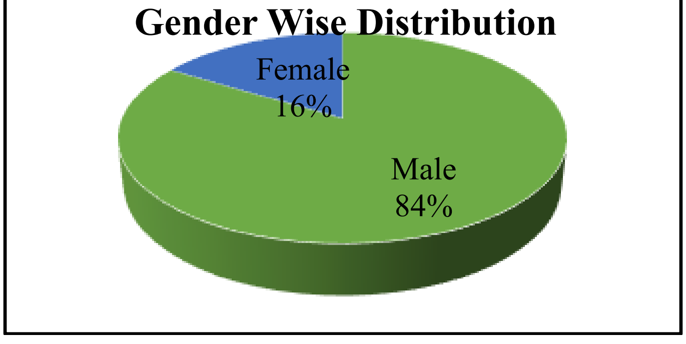
This questionnaire developed on the above grounds was exercised in a face to face interaction with the respondents, though in some of the cases the questionnaires were also mailed to the respondents and the responses collected thereof.

Statistical Analysis

The data collected by the use of above questionnaire was analyzed using SPSS Ver. 27.0, where the major statistical tool of data analysis were Binary Logistic Regression and Chi Square test.

Data Analysis and Interpretation

Figure 1: Gender Wise Ditribution

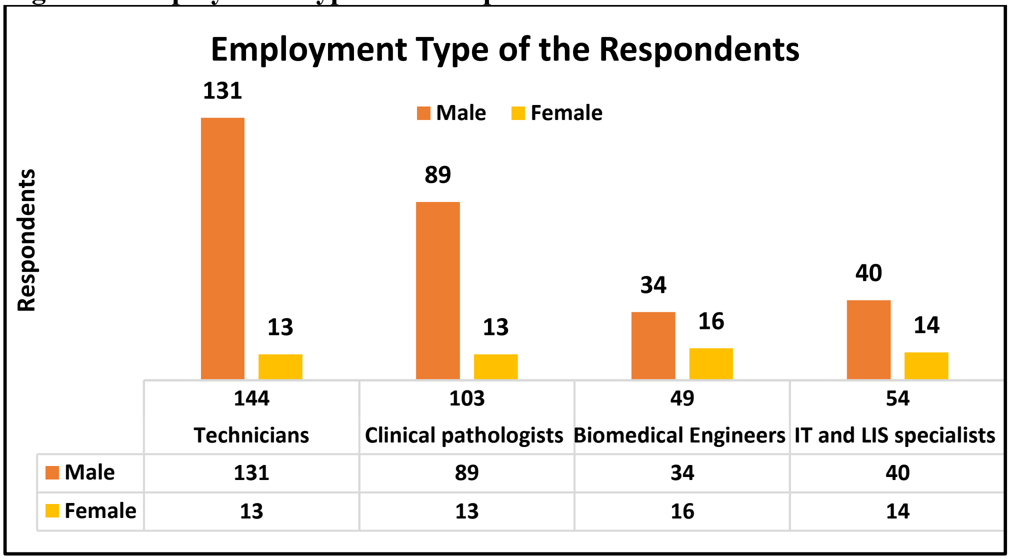


From the above pie chart it is clear that there were 84% of male respondents and 16% of Female respondents. As a matter of fact most of the male respondents were found in the urban areas and in most of the places the female respondents were engaged in administrative works only. Only in few of the laboratories, female respondents were working and technicians or bio-medical engineers.

Table1: Employment Type of the respondents

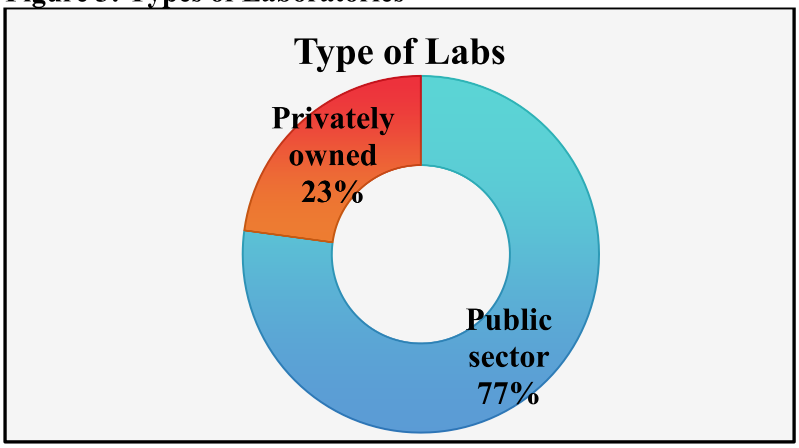
Employment Type	Respondents	Male	Female
Technicians	144	131	13
Clinical pathologists	103	89	13
Biomedical Engineers	49	34	16
IT and LIS specialists	54	40	14
Total	350	294	56

Figure 2: Employment Type of the respondents



As stated above in the above figure 2, there were four categories in which the respondents were employed, Technicians, Clinical pathologists, Biomedical Engineers and IT & LIS specialists. Again here it can be seen that for all the categories the number of male respondents was more than the female respondents. As a matter of fact there were 144 Technicians, 103 Clinical pathologists, 49 Biomedical Engineers and 54 IT & LIS specialists.

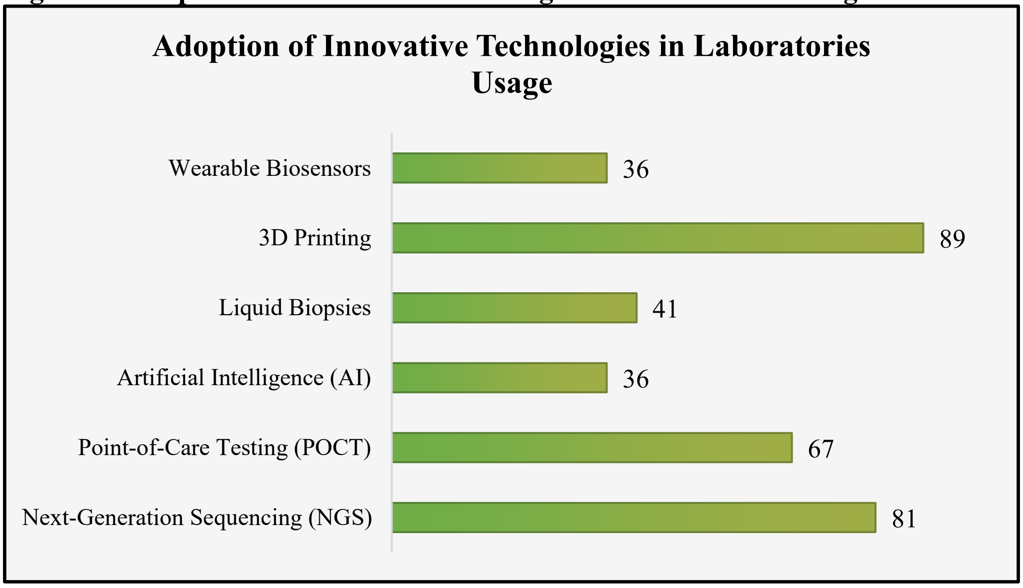
Figure 3: Types of Laboratories



Out of the total laboratories, 77% of the labs were owned by the public section authorities and only 23% were owned my the private sector players. This shows that public sector is dominating in case of pathology, medicinal development and other related aspects. Then most of he private sector labs were related to foreign brands, as the govt. Agencies are collaborating with foreign players also.

Table 2: Adoption of Innovative Technologies in Laboratories		
Technology	**Usage**	**%**
Next-Generation Sequencing (NGS)	81	23.1
Point-of-Care Testing (POCT)	67	19.1
Artificial Intelligence (AI)	36	10.3
Liquid Biopsies	41	11.7
3D Printing	89	25.4
Wearable Biosensors	36	10.3
Total	**350**	**100.0**

Figure 4: Adoption of Innovative Technologies in Laboratories Usage



The level of awareness is certainly high for the available technologies, but then again usage and adoption of the same is variable. Like 25% of the respondents have used the technology of 3D printing, 23% have used the NGS, 19% have used the POCT and 11% have used the liquid biopsies. Finally AI and wearable biosensors were used by 10% each. Here it is important to mention that most of the respondents were using AI in the indirect manner, like record keeping, patient reports, sharing of information with stakeholder but then again the direct usage of the same is still required to be evolved.

Test of Hypothesis

Researcher has applied Binary Logistic Regression, this is a statistical technique called binary logistic regression predicts the likelihood of a result by modeling the relationship between independent factors and a binary dependent variable (one with two possible outcomes, such as yes/no or pass/fail). In contrast to linear regression, which forecasts a continuous result, logistic regression maps the linear combination of predictors onto a probability between 0 and 1, producing a sigmoid (S-shaped) curve that is appropriate for classification problems like determining if an email is spam or not.

In this present study the application of this test will identify the predictors of technology adoption in laboratories from different regions of Saudi Arabia.

Details of dependent and independent variables are given below:

a. Dependent Variable: Adoption of innovative technology (Yes = 1, No = 0).

b. Independent Variables:

i. Institutional type

ii. Prior training

iii. Age

iv. Professional role

Table 3: Result of binary Logistic Regression

Predictor	Odds Ratio (OR)	95% CI	p-value
Institutional Type	2.21	1.32–3.47	< 0.01
Prior Training	1.65	1.21–2.95	< 0.01
Age	0.82	0.93–0.99	0.12
Role (Technologist)	1.50	0.91–2.21	0.13

*Model Fit: Nagelkerke $R^2 = 0.21$

Interpretation

As can be seen from the above table 3 stating the result of Binary Logistic Regression, the results state that the institutional type and prior training were significant predictors, as far as adoption of technology is concerned. Then on the other hand the component of age and role of respondent present a slight negative slope. This can be interpreted that in the present data set the younger age group has generally adopted the new and innovative technology as compared to senior or higher age groups.

Results from Chi Square Test

Then for finding the variation in responses of the sample units the researcher had applied Chi Square test. The components tested were barriers or challenges in knowledge upgrade, training concerns and respective usage of technology. These components will be tested on the grounds of age and and role of the respondents.

Summary of Chi Square Test Results

	Adoption of Technology							
	On the Basis of Age of the Respondents				**On the Basis of Role of the Respondent**			
	NGS	POCT	Liquid Biopsies	Wearable Biosensors	NGS	POCT	Liquid Biopsies	Wearable Biosensors
Calculated Value	1..435	.732	.677	.213	.317	.562	.551	.821
Table Value	2.550	1.764	.682	.337	.421	.664	.673	.854
	Training and Development							
	On the Basis of Age of the Respondents				**On the Basis of Role of the Respondent**			
	Training	Training Update	On the job Training	Certifications	Training	Training Update	On the job Training	Certifications
Calculated Value	.923	.264	.939	.057	1.832	.520	.692	.832

Table Value	.805	.551	1.325	.460	.971	.734	.893	1.751

Interpretation

In case of Chi Square test the variation in Observed and expected values is being tested, here the observed values are the calculated values and the expected values are the table values. Now if all the table values are greater than the expected values then the hypothesis is accepted or else rejected. Considering this thumb rule, the results given in the above table are being evaluated.

As can be seen from the above results that for adoption of technology, in most of the cases the table value is greater than the calculated value, this shows that the level of awareness of the respondents was high, then on the other hand for the training and development part there is slight variation in the results. The same was visible in the earlier performed Binary Logistic regression as well. Like under the section of age of the respondents, for training the calculated value was .923 and the table value was .805. then under the section of role of the respondents again for training the calculated value was 1.832 and table value was .971.

As a matter of fact the level of variation is not too high, but this shows that there is some lack on the grounds of training and development of the laboratory staff. It was visible in the field survey that many of the Urban Rural labs have started to integrate the innovative technologies in their respective labs but the process of training and development of the staff is comparatively slow. There are two reason of this variation, firstly the technology at the international level is changing very fast and at the global level every time new updates are coming in, but in the rural and semi urban areas the technology related infrastructure is still in development stage. Secondly the resources available at the local level are not supportive enough to deal with the ever changing technology.

Results

As per the results of above Chi Square test and Binary Logistic test it can be stated that the innovative technologies are getting implemented in the medical laboratories, with some lack on the ground of the training, laboratory staff was found to be aware of the innovative technologies and is in the process of adopting it. Hence the null hypothesis 'The adoption of innovative technological components in laboratory medicine is significantly associated with the improved work flow and test results of the selected laboratories in Saudi Arabia.' can be accepted and the alternate hypothesis is rejected.

Conclusion

A major change in the diagnostic medicine landscape, the incorporation of automation into clinical laboratory procedures offers great promise to improve accuracy and efficiency. The study's findings demonstrate that new developments in laboratory automation are not only incidental enhancements but are radically altering the way labs function, which has an immediate impact on patient care and health results.Advanced robots, artificial intelligence, and data analytics are just a few examples of the automation technologies that are simplifying processes, reducing human error, and speeding up turnaround times. The fast-paced, high-demand field of clinical diagnostics depends on these advancements to assure more consistent and reliable results and to support high-throughput processing.

Additionally, automation allows labs to manage growing test volumes without incurring corresponding labor expenditures, maximizing resource utilization and enhancing cost effectiveness.The integration of end-to-end automated technologies and the decrease in manual sample handling improve laboratory safety by reducing exposure to potentially dangerous compounds. Additionally, predicted diagnostics and tailored therapy are made possible by the increasing integration of machine learning algorithms into laboratory procedures. This enhances test sensitivity and specificity while creating new opportunities for preventative healthcare approaches.The shift to completely automated labs is not without its difficulties, though. Careful consideration must be given to the initial investment expenses, the modernization of the current infrastructure, and the ongoing training of staff to operate with cutting-edge equipment. Furthermore, strong data security measures are necessary for the integration of new technologies in order to guarantee patient data privacy and regulatory compliance.

References

1. Wilson S, Steele S, Adeli K. Innovative technological advancements in laboratory medicine: predicting the lab of the future. Biotechnol Biotechnol Equip. 2022;36(S1):S9–S21.
2. Alghamdi AA, Alzahrani A, Alotaibi M. Implementation of laboratory automation in Saudi hospitals: impact on workflow and diagnostic accuracy. Saudi Med J. 2022;43(5):512–8.
3. Al-Mohaimeed A, Al-Saadi M. Artificial intelligence in Saudi clinical laboratories: current status and future prospects. J Infect Public Health. 2021;14(3):345–50.
4. Adeli K, Wong SL, Chan MK. Pediatric laboratory medicine: current challenges and future opportunities. Clin Biochem. 2020;83:18–26.
5. Alshammari TM, Alhassan AM, Alzahrani MA. Integration of molecular diagnostics in Saudi Arabia's cancer centers: a national survey. J Cancer Policy. 2023;39:100423.
6. Kiechle FL, Maines R. Laboratory automation: past, present, and future. Clin Lab Med. 2019;39(1):1–15.
7. Al-Tawfiq JA, Memish ZA. Point-of-care testing in Saudi Arabia: expanding access to diagnostics. Int J Infect Dis. 2020;95:1–4.
8. Plebani M. Laboratory medicine: the challenge of intelligent automation. Clin Chem Lab Med. 2019;57(5):617–27.
9. Alqahtani F, Alharbi R, Alghamdi H. Digital pathology adoption in Saudi tertiary hospitals: a cross-sectional study. J Pathol Inform. 2022;13:45.
10. Lippi G, Plebani M. Laboratory medicine in the era of artificial intelligence. Clin Chem Lab Med. 2020;58(1):1–2.
11. Alzahrani A, Alotaibi N. Blockchain applications in Saudi laboratory data management: a feasibility study. Health Informatics J. 2023;29(2):146–54.
12. Pantanowitz L, Sharma A, Carter AB. Twenty years of digital pathology: an overview of the evolution and future. J Pathol Inform. 2020;11:40.
13. Al-Mutairi M, Al-Dossary R. Wearable biosensors in Saudi clinical monitoring: a pilot evaluation. Saudi J Health Sci. 2021;10(2):89–94.
14. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. Nat Med. 2019;25(1):44–56.
15. Alhassan AM, Alshammari TM. CRISPR-based diagnostics in Saudi research labs: current applications and ethical concerns. Saudi J Biol Sci. 2022;29(6):1032–8.
16. Chan MK, Adeli K. The role of laboratory medicine in precision health. Clin Biochem. 2021;89:1–3.
17. Alotaibi Y, Alghamdi S. Microfluidics in Saudi diagnostic labs: a review of emerging applications. J Med Devices. 2022;16(3):031101.
18. Ghaffar A, Reddy KS, Singhi M. Health technology assessment in developing countries: a global perspective. Lancet Glob Health. 2020;8(6):e754–e755.
19. Alzahrani M, Alshahrani A. 3D printing in Saudi laboratory education: bridging theory and practice. J Med Educ Curric Dev. 2021;8:238212052110234.
20. Adeli K. Big data and laboratory medicine: opportunities and challenges. Clin Chem. 2020;66(1):4–6.
21. Al-Mazrou YY, Al-Ghamdi AS. Laboratory information systems in Saudi Arabia: current status and future directions. Health Informatics J. 2020;26(4):2762–70.
22. Lippi G, Plebani M. Laboratory medicine resilience during COVID-19: lessons learned. Clin Chem Lab Med. 2021;59(7):1203–7.
23. Alshahrani M, Alqahtani T. AI-based hematology analyzers in Saudi labs: performance evaluation. Hematol Transfus Int J. 2022;10(1):1–6.
24. Plebani M. Harmonization in laboratory medicine: the complete picture. Clin Chem Lab Med. 2020;58(1):1–6.

25. Al-Harbi S, Al-Mutairi N. Telepathology in Saudi Arabia: improving access to histopathology services. J Telemed Telecare. 2023;29(1):45–52.