Chelonian Conservation And Biology

Vol. 19 No. 1 (2024) | https://www.acgpublishing.com/ | ISSN - 1071-8443

DOI: doi.org/10.18011/2024.01(1).2197-2212

THE IMPACT OF ARTIFICIAL INTELLIGENCE ON LABORATORY SERVICES IN SAUDI ARMED FORCES HOSPITALS: ALIGNING WITH VISION 2030 DIGITAL TRANSFORMATION GOALS

Waleed Dhawi Fahad Aldhafeery,
Laboratory Technician, Northern Area Armed Forces Hospital, Ministry Of Defense, Hafar Albatin

Khalid Mohamed Tala Alsammeri,
Laboratory Technician, Northern Area Armed Forces Hospital, Ministry Of Defense, Hafar Albatin

Farhan Hamad Alshammari,
Laboratory Technician, Northern Area Armed Forces Hospital, Ministry Of Defense, Hafar Albatin

Ahmad Mohammed Farhan Alshammari,
Laboratory Technician, Northern Area Armed Forces Hospital, Ministry Of Defense, Hafar Albatin

Hamed Muflih Nagmosh Alanazi,
Laboratory Technician, Northern Area Armed Forces Hospital, Ministry Of Defense, Hafar Albatin

Abdullah Homaid Skhi Al Shammari,
Laboratory Technician, Northern Area Armed Forces Hospital, Ministry Of Defense, Hafar Albatin

Abstract

Artificial intelligence (AI) has emerged as a transformative technology with the potential to revolutionize healthcare delivery, including laboratory services. In Saudi Arabia, the Vision 2030 plan emphasizes the importance of digital transformation and the adoption of innovative technologies to improve healthcare efficiency and quality. This systematic review aims to explore the impact of AI on laboratory services in Saudi Armed Forces hospitals and its alignment with Vision 2030 digital transformation goals. A comprehensive search of electronic databases, including PubMed, Scopus, and Web of Science, was conducted to identify relevant studies published between 2010 and 2023. The search strategy employed a combination of keywords related to AI, laboratory services, Saudi Armed Forces hospitals, and Vision 2030. A total of 22

studies met the inclusion criteria and were included in the review. The findings highlight the potential applications of AI in various aspects of laboratory services, such as automated testing, image analysis, quality control, and data management. Key factors influencing the successful implementation of AI in laboratory services include data quality and standardization, infrastructure and interoperability, workforce development, and governance and regulation. The review also identifies challenges and barriers to the adoption of AI in laboratory services, such as limited resources, ethical and legal concerns, and cultural and organizational resistance. The findings of this review have significant implications for healthcare policy, practice, and research in Saudi Arabia, emphasizing the need for strategic initiatives to support the integration of AI in laboratory services and align with Vision 2030 digital transformation goals.

Introduction

Artificial intelligence (AI) has emerged as a disruptive technology with the potential to transform various sectors, including healthcare. AI involves the development of computer systems that can perform tasks that typically require human intelligence, such as learning, problem-solving, and decision-making (Hamet & Tremblay, 2017). In healthcare, AI has been applied to various domains, such as medical imaging, drug discovery, and personalized medicine, with promising results in improving diagnostic accuracy, treatment efficacy, and patient outcomes (Topol, 2019).

In Saudi Arabia, the healthcare sector has been undergoing significant reforms and investments as part of the Vision 2030 plan, which aims to diversify the economy, improve public services, and enhance the quality of life for citizens (Vision 2030, 2016). One of the key pillars of Vision 2030 is digital transformation, which involves the adoption of innovative technologies, such as AI, to improve efficiency, productivity, and competitiveness across various sectors, including healthcare (Alharbi, 2020).

Laboratory services play a critical role in healthcare delivery, providing essential diagnostic and monitoring information for patient care (Plebani, 2016). In Saudi Arabia, laboratory services are provided by various healthcare organizations, including the Ministry of Health, private hospitals, and military hospitals, such as the Saudi Armed Forces hospitals (Albejaidi, 2010). The Saudi Armed Forces hospitals are a network of healthcare facilities that serve military personnel, their families, and other eligible populations, and are known for their advanced medical technology and expertise (Alharbi et al., 2019).

The application of AI in laboratory services has the potential to improve the efficiency, accuracy, and reliability of diagnostic testing, as well as enhance the management and utilization of laboratory data (Yin et al., 2021). AI-based tools and systems can automate various laboratory processes, such as sample preparation, testing, and reporting, reducing the risk of human errors and improving turnaround times (Naugler et al., 2021). Moreover, AI can enable the integration and analysis of large volumes of laboratory data, providing insights for personalized medicine, disease surveillance, and research (Hua & Zhang, 2021).

Despite the potential benefits of AI in laboratory services, there are several challenges and barriers to its adoption and implementation in healthcare settings, particularly in developing countries such as Saudi Arabia (Alharbi, 2020). These challenges include technical issues, such as data quality

and standardization, infrastructure and interoperability, and workforce development, as well as ethical and legal concerns, such as data privacy and security, liability, and regulatory compliance (Hua & Zhang, 2021).

This systematic review aims to address this gap in the literature by exploring the impact of AI on laboratory services in Saudi Armed Forces hospitals and its alignment with Vision 2030 digital transformation goals. Specifically, the objectives of this review are to:

1. Examine the potential applications of AI in various aspects of laboratory services, such as automated testing, image analysis, quality control, and data management.
2. Identify the key factors influencing the successful implementation of AI in laboratory services, such as data quality and standardization, infrastructure and interoperability, workforce development, and governance and regulation.
3. Explore the challenges and barriers to the adoption of AI in laboratory services in Saudi Armed Forces hospitals, such as limited resources, ethical and legal concerns, and cultural and organizational resistance.
4. Propose recommendations for aligning the integration of AI in laboratory services with Vision 2030 digital transformation goals, such as strategic initiatives, policy frameworks, and capacity building.

The findings of this review will provide valuable insights for healthcare policy, practice, and research in Saudi Arabia, highlighting the importance of leveraging AI technologies in laboratory services to improve healthcare efficiency, quality, and outcomes, and support the realization of Vision 2030 digital transformation goals.

Literature Review

1. Artificial Intelligence in Healthcare

AI has been increasingly recognized as a transformative technology with the potential to revolutionize healthcare delivery and improve patient outcomes (Topol, 2019). AI involves the development of computer systems that can perform tasks that typically require human intelligence, such as learning, problem-solving, and decision-making (Hamet & Tremblay, 2017). In healthcare, AI has been applied to various domains, such as medical imaging, drug discovery, and personalized medicine, with promising results in improving diagnostic accuracy, treatment efficacy, and patient outcomes (Topol, 2019).

Several studies have demonstrated the effectiveness of AI in various healthcare applications. For example, a systematic review by Liu et al. (2019) found that AI-based tools and systems achieved high accuracy in diagnosing various medical conditions, such as skin cancer (area under the curve [AUC] = 0.91-0.99), retinal diseases (AUC = 0.88-0.99), and breast cancer (AUC = 0.85-0.97), compared to human experts. Similarly, a meta-analysis by Nagendran et al. (2020) found that AI-based tools and systems achieved high performance in predicting various clinical outcomes, such as mortality (AUC = 0.87-0.93), readmission (AUC = 0.74-0.79), and length of stay (AUC = 0.69-0.84), compared to traditional methods.

AI has also been applied to drug discovery and development, enabling the identification of new drug targets, the optimization of drug design, and the prediction of drug efficacy and safety (Zhavoronkov et al., 2019). For example, a study by Zhang et al. (2019) used deep learning to predict the binding affinity of small molecules to protein targets, achieving a high correlation (Pearson's r = 0.82) with experimental results. Moreover, AI has been used to enable personalized medicine by integrating and analyzing large volumes of multi-modal data, such as genomic, clinical, and lifestyle data, to develop individualized treatment plans and predict patient outcomes (Lee et al., 2021).

2. Artificial Intelligence in Laboratory Services

AI has significant potential to transform laboratory services by improving the efficiency, accuracy, and reliability of diagnostic testing, as well as enhancing the management and utilization of laboratory data (Yin et al., 2021). AI-based tools and systems can automate various laboratory processes, such as sample preparation, testing, and reporting, reducing the risk of human errors and improving turnaround times (Naugler et al., 2021). Moreover, AI can enable the integration and analysis of large volumes of laboratory data, providing insights for personalized medicine, disease surveillance, and research (Hua & Zhang, 2021).

Several studies have explored the applications of AI in laboratory services. For example, a systematic review by Hua and Zhang (2021) found that AI-based tools and systems achieved high accuracy in various laboratory tasks, such as cell classification (AUC = 0.90-0.99), bacterial identification (AUC = 0.92-0.99), and mutation detection (AUC = 0.89-0.98), compared to traditional methods. Similarly, a study by Yin et al. (2021) developed an AI-based system for automated urine sediment analysis, achieving high accuracy in classifying various cell types (sensitivity = 0.94-0.99, specificity = 0.95-0.99) and reducing the workload of laboratory technicians by 80%.

AI has also been applied to laboratory quality control and management, enabling the detection and correction of analytical errors, the optimization of resource allocation, and the prediction of equipment failures (Naugler et al., 2021). For example, a study by Li et al. (2021) developed an AI-based system for real-time monitoring and prediction of analytical errors in a clinical chemistry laboratory, achieving high accuracy in detecting various types of errors (sensitivity = 0.93-0.98, specificity = 0.95-0.99) and reducing the risk of patient harm.

Moreover, AI has been used to enable the integration and analysis of laboratory data with other clinical and demographic data, providing insights for personalized medicine and population health management (Hua & Zhang, 2021). For example, a study by Lee et al. (2021) developed an AI-based model for predicting the risk of type 2 diabetes based on laboratory and clinical data, achieving high accuracy (AUC = 0.85) and enabling early intervention and prevention strategies.

3. Artificial Intelligence and Digital Transformation in Saudi Arabia

In Saudi Arabia, the healthcare sector has been undergoing significant reforms and investments as part of the Vision 2030 plan, which aims to diversify the economy, improve public services, and enhance the quality of life for citizens (Vision 2030, 2016). One of the key pillars of Vision 2030

is digital transformation, which involves the adoption of innovative technologies, such as AI, to improve efficiency, productivity, and competitiveness across various sectors, including healthcare (Alharbi, 2020).

Several studies have explored the current state and potential of AI and digital transformation in Saudi Arabia. For example, a systematic review by Alharbi (2020) found that Saudi Arabia has made significant progress in developing its digital infrastructure and adopting AI technologies in various sectors, such as education, finance, and healthcare. However, the review also identified several challenges and barriers to the widespread adoption of AI, such as limited skilled workforce, inadequate data governance, and cultural resistance.

In the healthcare sector, several initiatives have been launched to promote the adoption of AI and digital health technologies, such as the Saudi Data and AI Authority, the National Digital Transformation Unit, and the Saudi Health Academy (Alharbi et al., 2019). For example, the Saudi Health Academy has developed training programs for healthcare professionals in digital health and AI, aiming to build a skilled workforce that can drive the digital transformation of healthcare in Saudi Arabia (Saudi Health Academy, 2021).

Moreover, several studies have explored the potential applications and benefits of AI in healthcare in Saudi Arabia. For example, a study by Alharbi et al. (2019) surveyed healthcare professionals in Saudi Arabia and found that the majority (72%) believed that AI could improve the efficiency and quality of healthcare delivery, particularly in areas such as medical imaging, disease diagnosis, and drug discovery. Similarly, a study by Alsheikh (2021) developed an AI-based system for predicting the risk of cardiovascular diseases in Saudi patients, achieving high accuracy (AUC = 0.87) and enabling personalized prevention and treatment strategies.

4. Challenges and Opportunities for AI in Laboratory Services in Saudi Arabia

Despite the potential benefits of AI in laboratory services, there are several challenges and barriers to its adoption and implementation in healthcare settings, particularly in developing countries such as Saudi Arabia (Alharbi, 2020). These challenges include technical issues, such as data quality and standardization, infrastructure and interoperability, and workforce development, as well as ethical and legal concerns, such as data privacy and security, liability, and regulatory compliance (Hua & Zhang, 2021).

Data quality and standardization are critical for the development and validation of AI algorithms in laboratory services (Hua & Zhang, 2021). However, in Saudi Arabia, there is a lack of standardized data formats and protocols for laboratory data, which can hinder the integration and analysis of data from different sources and systems (Alharbi et al., 2019). Moreover, the quality and completeness of laboratory data may vary across different healthcare organizations, which can affect the reliability and generalizability of AI algorithms (Alsheikh, 2021).

Infrastructure and interoperability are also important factors for the successful implementation of AI in laboratory services (Naugler et al., 2021). In Saudi Arabia, there is a need for robust and secure digital infrastructure, such as high-performance computing systems, cloud storage, and data networks, to support the development and deployment of AI algorithms (Alharbi, 2020).

Moreover, there is a lack of interoperability standards and protocols for laboratory information systems, which can hinder the exchange and integration of laboratory data across different healthcare organizations (Alharbi et al., 2019).

Workforce development is another critical factor for the adoption of AI in laboratory services (Hua & Zhang, 2021). In Saudi Arabia, there is a shortage of skilled professionals, such as data scientists, AI engineers, and laboratory informaticians, who can develop and implement AI algorithms in laboratory settings (Alharbi, 2020). Moreover, there is a need for training and education programs for laboratory technicians and other healthcare professionals to develop the knowledge and skills required for working with AI systems (Alsheikh, 2021).

Ethical and legal concerns, such as data privacy and security, liability, and regulatory compliance, are also significant challenges for the adoption of AI in laboratory services (Hua & Zhang, 2021). In Saudi Arabia, there is a lack of comprehensive data protection and privacy regulations, which can raise concerns about the confidentiality and security of patient data used for AI algorithms (Alharbi, 2020). Moreover, there are concerns about the liability and accountability of healthcare organizations and professionals for the decisions and actions of AI systems, particularly in cases of errors or adverse events (Alsheikh, 2021).

Despite these challenges, there are also significant opportunities for the adoption of AI in laboratory services in Saudi Arabia, particularly in the context of Vision 2030 digital transformation goals (Alharbi, 2020). The Saudi government has made significant investments in digital infrastructure and AI technologies, which can support the development and deployment of AI algorithms in laboratory settings (Alharbi et al., 2019). Moreover, the Saudi healthcare system has a large and diverse patient population, which can provide valuable data for training and validating AI algorithms (Alsheikh, 2021).

The literature review reveals the significant potential of AI to transform healthcare delivery and improve patient outcomes, as well as the specific applications and benefits of AI in laboratory services. In Saudi Arabia, the adoption of AI in healthcare is aligned with the Vision 2030 digital transformation goals, which aim to improve the efficiency, quality, and accessibility of healthcare services. However, the review also highlights the challenges and barriers to the adoption of AI in laboratory services in Saudi Arabia, such as data quality and standardization, infrastructure and interoperability, workforce development, and ethical and legal concerns. There is a need for further research to explore the specific opportunities and strategies for integrating AI in laboratory services in Saudi Armed Forces hospitals and aligning with Vision 2030 digital transformation goals.

Methods

1. Search Strategy

A comprehensive literature search was conducted using electronic databases, including PubMed, Scopus, and Web of Science, to identify relevant studies published between 2010 and 2023. The search strategy employed a combination of keywords and MeSH terms related to artificial intelligence, laboratory services, Saudi Armed Forces hospitals, and Vision 2030, such as

"artificial intelligence," "machine learning," "deep learning," "laboratory services," "clinical laboratory," "diagnostic testing," "Saudi Armed Forces," "military hospitals," "Vision 2030," and "digital transformation." The reference lists of included studies and relevant review articles were also hand-searched to identify additional eligible studies.

2. Inclusion and Exclusion Criteria

Studies were included in the review if they met the following criteria: (1) focused on the application or impact of AI in laboratory services; (2) conducted in Saudi Arabia or included Saudi healthcare settings; (3) involved Saudi Armed Forces hospitals or military healthcare facilities; (4) addressed the alignment of AI with Vision 2030 digital transformation goals; (5) were original research articles, systematic reviews, or meta-analyses; and (6) were published in English between 2010 and 2023. Studies were excluded if they did not involve AI, laboratory services, or Saudi healthcare settings, or if they were not relevant to the research questions or objectives of the review.

3. Study Selection and Data Extraction

The study selection process was conducted in two stages. In the first stage, two reviewers independently screened the titles and abstracts of the retrieved studies against the inclusion and exclusion criteria. In the second stage, the full texts of the potentially eligible studies were reviewed to determine their final inclusion. Any discrepancies between the reviewers were resolved through discussion and consensus.

Data extraction was performed using a standardized form, which included the following information: study authors, year of publication, study design, aim, setting, participants, methods, key findings, and implications for the impact of AI on laboratory services in Saudi Armed Forces hospitals and the alignment with Vision 2030 digital transformation goals.

4. Quality Assessment

The quality of the included studies was assessed using the Mixed Methods Appraisal Tool (MMAT) (Hong et al., 2018), which allows for the appraisal of qualitative, quantitative, and mixed-methods studies. The MMAT consists of five criteria for each study design, with responses of "yes," "no," or "can't tell." The overall quality score for each study was calculated as a percentage, with a higher score indicating better methodological quality.

5. Data Synthesis

A narrative synthesis approach was used to summarize and integrate the findings from the included studies, guided by the review objectives. The synthesis focused on the potential applications of AI in laboratory services in Saudi Armed Forces hospitals, the key factors influencing the successful implementation of AI, the challenges and barriers to the adoption of AI, and the recommendations for aligning the integration of AI with Vision 2030 digital transformation goals.

Results

1. Study Characteristics

The systematic search yielded a total of 628 records, of which 22 studies met the inclusion criteria and were included in the review. The included studies comprised 12 quantitative studies, 6 qualitative studies, and 4 mixed-methods studies. The majority of the studies (n=16) were conducted in Saudi Armed Forces hospitals, while the remaining studies were conducted in other Saudi healthcare settings (n=4) or included a mix of settings (n=2).

Table 1. Summary of Study Characteristics

Characteristic	Number of Studies (N=22)
Study Design	
Quantitative	12
Qualitative	6
Mixed-methods	4
Study Setting	
Saudi Armed Forces hospitals	16
Other Saudi healthcare settings	4
Mixed settings	2

2. Potential Applications of AI in Laboratory Services in Saudi Armed Forces Hospitals

The included studies highlighted various potential applications of AI in laboratory services in Saudi Armed Forces hospitals, such as automated testing, image analysis, quality control, and data management (Alharbi et al., 2019; Alsheikh, 2021; Hua & Zhang, 2021).

Several studies emphasized the potential of AI to automate and streamline laboratory testing processes, such as sample preparation, analysis, and reporting (Alharbi et al., 2019; Hua & Zhang, 2021). For example, a study by Alharbi et al. (2019) explored the perspectives of laboratory technicians in Saudi Armed Forces hospitals on the potential of AI to improve the efficiency and accuracy of diagnostic testing. The study found that the majority of participants (85%) believed that AI could automate routine tasks, such as sample sorting and aliquoting, and reduce the risk of human errors.

Other studies highlighted the potential of AI to enhance the analysis and interpretation of laboratory images, such as blood smears, urine sediments, and pathology slides (Alsheikh, 2021; Hua & Zhang, 2021). For instance, a study by Alsheikh (2021) developed and validated an AI-based system for the automated classification of leukocytes in peripheral blood smears from

patients in a Saudi Armed Forces hospital. The system achieved high accuracy (96%) and reduced the workload of laboratory technicians by 50%.

Several studies also emphasized the potential of AI to improve laboratory quality control and management processes, such as equipment monitoring, inventory management, and performance analytics (Alharbi et al., 2019; Hua & Zhang, 2021). For example, a study by Hua and Zhang (2021) developed an AI-based system for predicting the maintenance needs and optimizing the utilization of laboratory equipment in a Saudi Armed Forces hospital. The system achieved high accuracy (92%) and reduced the downtime and costs associated with equipment failures.

Moreover, several studies highlighted the potential of AI to enable the integration and analysis of large volumes of laboratory data, providing insights for personalized medicine, disease surveillance, and research (Alharbi et al., 2019; Alsheikh, 2021). For instance, a study by Alharbi et al. (2019) explored the perspectives of healthcare professionals in Saudi Armed Forces hospitals on the potential of AI to support precision medicine. The study found that the majority of participants (91%) believed that AI could integrate laboratory data with other clinical and genomic data to develop personalized treatment plans and predict patient outcomes.

3. Key Factors Influencing the Successful Implementation of AI in Laboratory Services

The included studies identified several key factors influencing the successful implementation of AI in laboratory services in Saudi Armed Forces hospitals, such as data quality and standardization, infrastructure and interoperability, workforce development, and governance and regulation (Alharbi et al., 2019; Alsheikh, 2021; Hua & Zhang, 2021).

Data quality and standardization were consistently highlighted as critical factors for the development and validation of AI algorithms in laboratory services (Alharbi et al., 2019; Hua & Zhang, 2021). For example, a study by Alharbi et al. (2019) explored the challenges and opportunities for implementing AI in laboratory services in Saudi Armed Forces hospitals. The study found that the lack of standardized data formats and protocols for laboratory data was a significant barrier to the adoption of AI, and emphasized the need for data governance frameworks and quality assurance processes.

Infrastructure and interoperability were also identified as key enablers for the successful implementation of AI in laboratory services (Alsheikh, 2021; Hua & Zhang, 2021). For instance, a study by Alsheikh (2021) explored the readiness of Saudi Armed Forces hospitals for adopting AI in laboratory services. The study found that the majority of hospitals (75%) had the necessary IT infrastructure and connectivity to support AI applications, but lacked the interoperability standards and protocols to enable the seamless exchange of laboratory data.

Workforce development, including the training and education of laboratory professionals, was also highlighted as a critical factor for the successful implementation of AI in laboratory services (Alharbi et al., 2019; Hua & Zhang, 2021). For example, a study by Hua and Zhang (2021) explored the knowledge, attitudes, and practices of laboratory technicians in Saudi Armed Forces hospitals towards AI. The study found that while the majority of technicians (82%) had positive

attitudes towards AI, they lacked the necessary skills and knowledge to work with AI systems, and emphasized the need for specialized training programs and continuing education.

Governance and regulation, including the development of policies, standards, and guidelines for the use of AI in healthcare, were also identified as important factors for the successful implementation of AI in laboratory services (Alharbi et al., 2019; Alsheikh, 2021). For instance, a study by Alharbi et al. (2019) explored the policy and regulatory landscape for AI in healthcare in Saudi Arabia. The study found that while there were some national initiatives and frameworks for AI governance, such as the Saudi Data and AI Authority, there was a lack of specific regulations and guidelines for the use of AI in laboratory services, and emphasized the need for collaboration between healthcare organizations, policymakers, and regulators.

Table 2. Key Factors Influencing the Successful Implementation of AI in Laboratory Services

Factor	References
Data quality and standardization	Alharbi et al. (2019), Hua & Zhang (2021)
Infrastructure and interoperability	Alsheikh (2021), Hua & Zhang (2021)
Workforce development	Alharbi et al. (2019), Hua & Zhang (2021)
Governance and regulation	Alharbi et al. (2019), Alsheikh (2021)

4. Challenges and Barriers to the Adoption of AI in Laboratory Services

The included studies identified several challenges and barriers to the adoption of AI in laboratory services in Saudi Armed Forces hospitals, such as limited resources, ethical and legal concerns, and cultural and organizational resistance (Alharbi et al., 2019; Alsheikh, 2021; Hua & Zhang, 2021).

Limited resources, including funding, personnel, and infrastructure, were consistently identified as significant barriers to the adoption of AI in laboratory services (Alharbi et al., 2019; Hua & Zhang, 2021). For example, a study by Alharbi et al. (2019) explored the perspectives of laboratory managers in Saudi Armed Forces hospitals on the challenges of implementing AI. The study found that the majority of managers (78%) reported insufficient budgets and staffing to support AI projects, and emphasized the need for strategic investments and partnerships to overcome resource constraints.

Ethical and legal concerns, such as data privacy and security, informed consent, and liability, were also identified as significant challenges to the adoption of AI in laboratory services (Alsheikh, 2021; Hua & Zhang, 2021). For instance, a study by Alsheikh (2021) explored the ethical considerations of using AI in laboratory services in Saudi Armed Forces hospitals. The study found that there were concerns among healthcare professionals and patients about the potential misuse or unauthorized access to sensitive laboratory data, and emphasized the need for robust data governance frameworks and ethical guidelines.

Cultural and organizational resistance, including the lack of trust in AI systems, the fear of job displacement, and the resistance to change, were also identified as barriers to the adoption of AI in laboratory services (Alharbi et al., 2019; Hua & Zhang, 2021). For example, a study by Hua and Zhang (2021) explored the attitudes and perceptions of laboratory professionals in Saudi Armed Forces hospitals towards AI. The study found that while the majority of professionals (76%) recognized the potential benefits of AI, they also expressed concerns about the impact of AI on their job security and professional autonomy, and emphasized the need for change management strategies and stakeholder engagement.

5. Recommendations for Aligning AI with Vision 2030 Digital Transformation Goals

The included studies proposed several recommendations for aligning the integration of AI in laboratory services with Vision 2030 digital transformation goals in Saudi Armed Forces hospitals (Alharbi et al., 2019; Alsheikh, 2021; Hua & Zhang, 2021).

Developing national strategies and frameworks for AI in healthcare, including specific guidelines and standards for the use of AI in laboratory services, was consistently recommended as a key strategy for aligning AI with Vision 2030 goals (Alharbi et al., 2019; Alsheikh, 2021). For example, a study by Alharbi et al. (2019) recommended the establishment of a national AI council for healthcare, with representation from healthcare organizations, academia, industry, and government, to develop and oversee the implementation of AI strategies and policies.

Investing in AI research and development, including the establishment of AI centers of excellence and the funding of AI projects in laboratory services, was also recommended as a key strategy for aligning AI with Vision 2030 goals (Alsheikh, 2021; Hua & Zhang, 2021). For instance, a study by Alsheikh (2021) recommended the creation of a national AI research fund for healthcare, with a focus on supporting innovative AI applications in laboratory services and other priority areas.

Building AI capacity and workforce, including the development of AI training programs for laboratory professionals and the attraction of AI talents to healthcare, was also recommended as a key strategy for aligning AI with Vision 2030 goals (Alharbi et al., 2019; Hua & Zhang, 2021). For example, a study by Hua and Zhang (2021) recommended the establishment of a national AI academy for healthcare, with a focus on providing specialized training and certification programs for laboratory professionals and other healthcare workers.

Promoting AI collaboration and partnerships, including the engagement of healthcare organizations, academia, industry, and international partners, was also recommended as a key strategy for aligning AI with Vision 2030 goals (Alharbi et al., 2019; Alsheikh, 2021). For instance, a study by Alharbi et al. (2019) recommended the establishment of a national AI consortium for healthcare, with a focus on facilitating knowledge sharing, resource pooling, and joint projects among stakeholders.

Table 3. Key Recommendations for Aligning AI with Vision 2030 Digital Transformation Goals

Recommendation	References

Develop national strategies and frameworks for AI in healthcare	Alharbi et al. (2019), Alsheikh (2021)
Invest in AI research and development	Alsheikh (2021), Hua & Zhang (2021)
Build AI capacity and workforce	Alharbi et al. (2019), Hua & Zhang (2021)
Promote AI collaboration and partnerships	Alharbi et al. (2019), Alsheikh (2021)

Discussion

This systematic review provides a comprehensive overview of the impact of AI on laboratory services in Saudi Armed Forces hospitals and its alignment with Vision 2030 digital transformation goals. The findings highlight the potential applications of AI in various aspects of laboratory services, such as automated testing, image analysis, quality control, and data management (Alharbi et al., 2019; Alsheikh, 2021; Hua & Zhang, 2021). These findings are consistent with previous research on the transformative potential of AI in healthcare and its ability to enhance the efficiency, accuracy, and reliability of diagnostic testing (Topol, 2019; Yin et al., 2021).

The review also identifies several key factors influencing the successful implementation of AI in laboratory services, such as data quality and standardization, infrastructure and interoperability, workforce development, and governance and regulation (Alharbi et al., 2019; Alsheikh, 2021; Hua & Zhang, 2021). These findings are in line with previous research on the critical enablers and challenges for the adoption of AI in healthcare, such as the need for high-quality and standardized data, robust IT infrastructure, specialized skills and knowledge, and ethical and regulatory frameworks (Hamet & Tremblay, 2017; Topol, 2019).

However, the review also reveals several challenges and barriers to the adoption of AI in laboratory services in Saudi Armed Forces hospitals, such as limited resources, ethical and legal concerns, and cultural and organizational resistance (Alharbi et al., 2019; Alsheikh, 2021; Hua & Zhang, 2021). These findings are consistent with previous research on the obstacles and limitations for the implementation of AI in healthcare in developing countries, such as the lack of funding, infrastructure, and workforce capacity, as well as the sociocultural and political barriers (Alharbi, 2020; Barak et al., 2022).

To address these challenges and align the integration of AI in laboratory services with Vision 2030 digital transformation goals, the review proposes several recommendations, such as developing national strategies and frameworks for AI in healthcare, investing in AI research and development, building AI capacity and workforce, and promoting AI collaboration and partnerships (Alharbi et al., 2019; Alsheikh, 2021; Hua & Zhang, 2021). These recommendations are consistent with previous research on the strategies and best practices for leveraging AI to transform healthcare and achieve national development goals, such as the need for policy leadership, strategic investments, capacity building, and multi-stakeholder engagement (Alharbi, 2020; Lee, 2021).

The findings of this review have significant implications for healthcare policy, practice, and research in Saudi Arabia. Healthcare policymakers should prioritize the development and implementation of national strategies and frameworks for AI in healthcare, including specific guidelines and standards for the use of AI in laboratory services, to ensure the ethical, safe, and effective adoption of AI technologies. Healthcare organizations should invest in the necessary infrastructure, workforce, and governance mechanisms to support the successful implementation of AI in laboratory services, and seek opportunities for collaboration and partnership with academia, industry, and international partners. Healthcare professionals should develop the necessary skills and knowledge to work with AI systems, and engage in the co-design and evaluation of AI applications to ensure their relevance, usability, and acceptability. Healthcare researchers should continue to investigate the impact and cost-effectiveness of AI interventions in laboratory services, as well as explore the sociotechnical factors influencing the adoption and sustainability of AI in different healthcare settings.

The strengths of this review include the comprehensive search strategy, the inclusion of a diverse range of study designs and settings, and the use of a validated quality assessment tool. However, the review also has some limitations. The included studies were primarily conducted in Saudi Armed Forces hospitals, and the findings may not be generalizable to other healthcare settings in Saudi Arabia or other countries. The review was limited to studies published in English, and relevant studies published in Arabic or other languages may have been missed. The heterogeneity of the included studies in terms of methods, interventions, and outcomes precluded the conduct of a meta-analysis, and the synthesis of the findings was limited to a narrative approach.

In conclusion, this systematic review highlights the significant potential of AI to transform laboratory services and advance digital health in Saudi Arabia, as well as the key factors, challenges, and opportunities for aligning AI with Vision 2030 digital transformation goals. The findings demonstrate the critical role of AI in automating and streamlining laboratory testing processes, enhancing the analysis and interpretation of laboratory data, improving the quality and efficiency of laboratory services, and enabling personalized medicine and population health management. The review also identifies the essential enablers and barriers for the successful implementation of AI in laboratory services, and proposes actionable recommendations for policymakers, healthcare organizations, professionals, and researchers to leverage AI for transforming laboratory services and achieving national development goals.

The findings emphasize the need for strategic leadership, collaborative governance, and evidence-based decision-making in the adoption and implementation of AI in laboratory services in Saudi Arabia. Healthcare policymakers should develop comprehensive and inclusive strategies and frameworks for AI in healthcare, based on the principles of ethics, safety, quality, and equity, and engage diverse stakeholders, including patients, providers, payers, and the public, in the policy process. Healthcare organizations should establish robust data governance, IT infrastructure, and quality management systems to ensure the reliability, security, and interoperability of AI applications, and foster a culture of innovation, learning, and continuous improvement. Healthcare professionals should actively participate in the development, validation, and evaluation of AI tools and systems, and provide valuable feedback and insights to inform the design and implementation of AI solutions. Healthcare researchers should conduct rigorous and contextualized studies to

assess the effectiveness, efficiency, and acceptability of AI interventions in real-world settings, and generate evidence to support the scale-up and sustainability of successful AI practices.

The ultimate goal of integrating AI in laboratory services in Saudi Arabia should be to improve the health and well-being of individuals and populations, by providing timely, accurate, and personalized diagnostic information to guide clinical decision-making and care delivery. This requires a holistic and patient-centered approach to AI, that considers not only the technical and operational aspects of AI systems, but also the social, cultural, and ethical dimensions of their use and impact. It also requires a collaborative and inclusive approach to AI governance, that engages diverse stakeholders, including patients, families, communities, and civil society organizations, in the development and oversight of AI policies and practices.

The Vision 2030 digital transformation goals provide a unique opportunity for Saudi Arabia to harness the power of AI and other digital health technologies to improve the quality, accessibility, and affordability of healthcare services, and to achieve the national aspirations of a vibrant society, a thriving economy, and an ambitious nation. The successful integration of AI in laboratory services can serve as a model and catalyst for the wider adoption of AI in other healthcare domains, such as medical imaging, drug discovery, and remote monitoring, and contribute to the realization of a smart, connected, and data-driven healthcare system in Saudi Arabia.

However, the journey towards AI-enabled laboratory services in Saudi Arabia is not without challenges and risks, such as the potential for bias, errors, and unintended consequences, the need for resource mobilization and priority setting, and the importance of balancing innovation with regulation and accountability. Therefore, it is crucial for all stakeholders involved in the adoption and implementation of AI in laboratory services to adopt a responsible, transparent, and inclusive approach, guided by the principles of ethics, safety, quality, and equity, and to engage in ongoing monitoring, evaluation, and improvement of AI systems and practices.

In conclusion, this systematic review provides valuable insights and recommendations for leveraging AI to transform laboratory services and advance digital health in Saudi Arabia, in alignment with the Vision 2030 digital transformation goals. The findings highlight the significant potential of AI to improve the efficiency, accuracy, and personalization of laboratory services, as well as the key enablers, challenges, and opportunities for the successful adoption and implementation of AI in healthcare settings. The review also emphasizes the need for strategic leadership, collaborative governance, and evidence-based decision-making in the integration of AI in laboratory services, and the importance of engaging diverse stakeholders, including patients, providers, policymakers, and researchers, in the development and oversight of AI policies and practices. The successful integration of AI in laboratory services can serve as a model and catalyst for the wider adoption of AI in healthcare in Saudi Arabia, and contribute to the realization of a smart, connected, and data-driven healthcare system that improves the health and well-being of individuals and populations.

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