Laboratory Automation and its Effects on Workflow Efficiency in Medical Laboratories

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DOI: https://doi.org/10.46431/MEJAST.2023.6407

ABSTRACT

This review aims to probe the impact of laboratory Automation on workflow effectiveness in medical laboratories. It explores the colorful aspects of laboratory Automation, including its benefits, challenges, and implicit Limitations. The study also delves into the different types of Automation Technologies generally used in medical laboratories, similar as robotics, Sample handling systems, and laboratory information operation systems. The exploration methodology includes a comprehensive literature review and Interviews with laboratory professionals to gather perceptivity and data on the Content. The findings suggest that laboratory Automation significantly improves Workflow effectiveness, leading to faster reversal times, reduced crimes, increased productivity, and bettered patient care. Still, certain challenges and considerations need to be addressed when enforcing Automation systems in medical laboratories. Overall, this exploration paper provides a comprehensive analysis of laboratory Automation and its effect on Workflow effectiveness in medical laboratories.

Keywords: Medical Laboratories; Automation Technologies; Work flow efficiency; Pre analytical.

1. Introduction

Medical laboratories play an essential role in the management of medical conditions by carrying out diagnostics tests, treatment control, prevention of various human pathologies, and providing precise results that help in the diagnosis, treatment and care of patients. These laboratory sets are responsible for analyzing various types of samples such as blood, urine samples, tissue samples and body fluids to detect anomalies, monitor diseases and evaluate overall health. Precision and efficiency in laboratory processes have a direct impact on patient outcomes and quality of healthcare [1, 9]. The proper functioning of a medical laboratory requires a well-coordinated and efficient workflow in conjunction with other services under a rigorous system that guarantees the quality of results in pre analytical, analysis and post analytical phases.

Therefore, the optimization of workflow efficiency in the medical laboratories is very important. Life science has transformed the healthcare system around the world, enabling all stakeholders such as clinicians, administrators and industry to make more informed decisions and empower patients to choose their health. As a result, India has emerged as one of the world’s leading hubs not only for medical tourism, but also for high-quality diagnostic services [2, 3, 4]. Medical laboratories play a critical role in patient care, providing essential diagnostic services that enable healthcare professionals to make accurate diagnoses, monitor disease progress, and evaluate treatment effectiveness. These laboratories are responsible for a wide range of diagnostic services, from clinical chemistry and hematology to microbiology and immunology, as well as molecular diagnostics. Test results are a major factor in the clinical decision-making process, accounting for approximately 70% of all clinical decisions [2, 3, 4].

The global test automation market is expected to be worth $5.5 billion by 2023 and grow at a compound annual growth rate (CAGR) of 9.3% during the forecast period. Due to the increasing demand for biopharmaceuticals, the number of laboratories offering analytical and product development solutions has increased worldwide. The automation market is expected to be worth $5.5 billion by 2023 and is expected to grow at a compound annual growth rate of 9.3% during the forecast period.
growth rate (CAGR) of 9.3% during the forecast period. Due to the increasing demand for biopharmaceuticals, the number of laboratories offering analytical and product development solutions has increased worldwide. Workflow efficiency in medical laboratories is the process of collecting specimens, processing them, and reporting and analyzing data in a timely and efficient manner \([6, 7, 9]\). Delayed or incorrect laboratory processes can result in diagnostic inaccuracies, delayed treatment, and a decrease in patient safety.

Table 1. Descriptive details of the benefit of administrating an efficient work flow

<table>
<thead>
<tr>
<th>Elements of Workflows</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>Faster Turnaround Time</td>
<td>Efficient workflows lead to quicker processing and analysis of specimens, resulting in faster turnaround times for test results.</td>
</tr>
<tr>
<td>Improved Patient Care</td>
<td>Efficient workflows contribute to accurate and reliable test results promptly, enhancing patient care through early detection and effective disease management.</td>
</tr>
<tr>
<td>Reduced Errors</td>
<td>Streamlined workflows minimize errors like mislabeling, sample mix-ups, or transcription mistakes, reducing incorrect diagnoses and treatment decisions.</td>
</tr>
<tr>
<td>Increased Productivity</td>
<td>Optimized workflow efficiency reduces delays and redundancies, enhancing staff productivity to handle a higher volume of tests efficiently.</td>
</tr>
<tr>
<td>Cost Savings</td>
<td>Efficient workflows minimize resource wastage, reduce retests due to errors, and optimize equipment usage, resulting in cost savings for the medical laboratory.</td>
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Despite the range of benefits that laboratory automation can bring, there remain a number of limitations. Integrating automation into a diagnostics laboratory is not in itself a guarantee of success and, where applied incorrectly can even result in a multitude of problems.

1.1. Laboratory Automation Significance

Automation is one of the greatest breakthroughs in the recent history of the diagnostics laboratory sciences. Laboratory automation began in the 1950s and has progressed throughout the decades to reduce the turnaround times in laboratory testing and eliminate the human errors. By replacing the repetitive and laborious manual processes involved in laboratory testing, automation has reduced the overall errors and allowed laboratory technicians to focus more time and energy on quality assurance \([8, 9, 10]\). Laboratory automation has been achieved using many types of instruments and equipment. Each automation system is chosen for individual laboratories based on their workflow and demand and is often described as the implications of technology and equipment to automate various laboratory processes, such as sample handling, testing, and result reporting. It involves the integration of robotics, computer software, and other technologies to streamline and improve
laboratory workflows [9, 10, 11]. The significance of laboratory automation lies in its ability to enhance efficiency, accuracy, and productivity in medical laboratories. By automating repetitive and time-consuming tasks, such as sample pipetting and plate handling, automation reduces the risk of errors and free laboratory staff to focus on more complex and value-added activities. Laboratory automation also enhances turnaround time by reducing the time required for sample processing and testing. This enables faster result reporting, which is crucial for timely clinical decision-making and patient management. Furthermore, automation helps standardize laboratory processes and reduce variability in test results. By eliminating manual steps and human intervention, automation minimizes the potential for human error and ensures consistent and reliable test performance [11, 12, 13]. Another important benefit of laboratory automation is its ability to handle high volumes of samples efficiently. Automated systems can process large numbers of samples simultaneously, increasing laboratory capacity and throughput. This is particularly valuable in situations where there is a high demand for testing, such as during disease outbreaks or in large healthcare facilities. Overall, clinical automation plays a vital role in improving the quality and efficiency of healthcare delivery. It allows medical laboratories to meet the increasing demands for diagnostic services while maintaining high standards of accuracy and reliability [13, 14, 15].

1.2. Benefits of Laboratory Automation

The integration of automation into the work environment has increased the efficiency, productivity, and effectiveness of many business processes. There are many pros and cons to integrating automation into the workplace, scientific process and summarizing them.

i. Increased Precision: Automation reduces human error by decreasing manual handling and increasing precision in sample processing and analysis, resulting in more consistent and reliable results [9, 14].

ii. Reduced turnaround time: Automation can streamline laboratory processes, such as sample preparation, analysis, and data management, leading to faster turnaround times for test results. This can be crucial in urgent or time-sensitive situations.

iii. Increased productivity: With automation, laboratories can handle a larger volume of samples in a shorter amount of time, increasing overall productivity. This can help meet the growing demand for laboratory services and reduce backlogs.

iv. Enhanced patient care: Faster turnaround times and increased accuracy in test results can contribute to better patient care. Physicians can make timely and informed decisions based on reliable laboratory data, leading to improved diagnosis and treatment.

v. Cost savings: While the initial investment in laboratory automation systems can be significant, they can result in long-term cost savings. Automation can reduce the need for manual labor, minimize reagent wastage, and optimize resource utilization, leading to overall cost efficiency.

vi. Standardization and quality control: Automation systems can enforce standardized protocols and ensure consistent performance across different laboratory processes. This can improve quality control measures and enhance their liability of laboratory results. It is significant to note that the implementation of laboratory automation requires careful planning, training, and validation to ensure it successful integration into existing
workflows. Additionally, ongoing maintenance and monitoring are essential to maximize the benefits of automation systems [15, 16].

1.3. Challenges and limitations associated with laboratory Automation

i. Cost: Implementing laboratory automation systems can be expensive, requiring significant upfront investment in equipment, software, and infrastructure. Additionally, there may be ongoing costs for maintenance, upgrades, and training [10, 15].

ii. Training: Laboratory staff may require extensive training to operate and maintain the automated systems effectively. This can involve learning new technologies, protocols, and troubleshooting procedures. Adequate training is crucial to ensure accurate and reliable results.

iii. System integration issues: Integrating automation systems into existing laboratory workflows and information management systems can be complex. Compatibility issues between different instruments, software and databases may arise, requiring careful planning and coordination [16, 17].

iv. Limited flexibility: Automation systems are designed to perform specific tasks efficiently and reliably. However, they may lack flexibility compared to manual methods, making it challenging to accommodate changes in testing requirements or adapt to new technologies [17, 18].

v. Technical failures: Like any complex machinery, automation systems can experience technical failures or malfunctions. This can disrupt laboratory operations and require prompt trouble shooting and repair to minimize downtime.

vi. Ethical considerations: Automation can reduce the need for human involvement in certain laboratory processes, potentially leading to job displacement. This raises ethical considerations. Regarding the impact on employment and the need for retraining or redeployment of affected staff [18, 19].

Table 2. Challenges in installing an efficient work flow in the diagnostics laboratory

<table>
<thead>
<tr>
<th>Challenges to Workflow Efficiency</th>
<th>Challenges</th>
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<tbody>
<tr>
<td>Manual Processes</td>
<td>Reliance on manual tasks like sample handling, data entry, and result reporting can introduce delays, transcription errors, and inconsistencies.</td>
</tr>
<tr>
<td>High Test Volume</td>
<td>Increasing demand for diagnostic tests can overload laboratory capacity, causing bottlenecks in workflows and longer turnaround times.</td>
</tr>
<tr>
<td>Complex Testing Procedures</td>
<td>Certain tests require multiple steps and specialized equipment, complicating workflows and increasing the likelihood of errors.</td>
</tr>
<tr>
<td>Regulatory Compliance</td>
<td>Compliance with regulatory standards, quality control, and accreditation requirements can add complexity to laboratory workflows, necessitating meticulous documentation.</td>
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</table>
1.4. Types of Laboratory Automation

1.4.1. Overview of notable different automation technologies used in medical laboratories, such as robotics, sample handling systems, and laboratory information management systems

i. Robotic automation: Robotic systems are used in laboratories to perform repetitive tasks such as pipetting, sample handling, and plate preparation. These systems can increase efficiency and accuracy by reducing human error and increasing throughput [19, 20].

ii. Sample handling systems: These systems automate the process of sample collection, transportation, and storage within the laboratory. They can include convey or belts, robotic arms, and automated storage and retrieval systems. These systems help to reduce manual handling and improve sample traceability.

iii. Laboratory information management systems (LIMS): LIMS are software solutions that automate the management of laboratory data, including sample tracking, result reporting, and quality control. They can integrate with other laboratory systems and provide real-time access to data for health care providers [11, 12, 18, 19].

Figure 1. Describing pictorial representation of the challenging factors associated with automation in laboratories

Figure 2. Depiction of various types of automation
iv. **Automated liquid handling systems**: Automate the process of pipetting and dispensing liquids in the laboratory. They can improve accuracy and precision, reduce contamination, and increase throughput of the data.

v. **Automatic analyzers**: These are specific instruments that automate the testing and analysis of samples. They can include automated chemistry analyzers, hematology analyzers, and molecular diagnostic platforms. These instruments can perform a wide range of tests with minimal human intervention henceforth can aid in less probation for contamination [19, 20, 21].

vi. **Automated specimen processing systems**: These systems automate the process of sample preparation, including centrifugation, aliquoting, and labeling. They can improve efficiency along with reducing manual handling errors. Overall, these automation technologies play a crucial role in improving the efficiency, accuracy, and reliability of clinical laboratory operations. They help to streamline workflows, reduce errors, and deliver timely and accurate test results to healthcare providers [21, 22].

2. **Researches on Automation systems and its benefits**

Many research studies indicate that the Medical laboratories with automation systems are more efficient, accurate, and reliable in their testing processes. This can lead to benefits for healthcare providers as well as patients, as they can reduce wait times and improve the quality of their test results. However, the initial investment can be costly, and it is important to carefully consider the costs and benefits before implementing an automation system [11, 14, 20, 21, 23]. Laboratory staff should also be involved in the decision making process and receive appropriate training and support throughout the implementation process. Integration with existing lab information management systems (IMS) or EHRs (Electronic Health Record) is also important, as it allows for the efficient management and reporting of data [21, 22]. It is also important to ensure that the different systems are compatible with each other and that the appropriate interfaces and software solutions are in place to ensure seamless integration. Finally, continuous monitoring and assessment of system performance as well as periodic maintenance and calibration are essential to ensure that the results are accurate and reliable. Evaluation of the impact of a total automation system in a large core laboratory on turnaround time. Overall, the research findings suggest that automation systems have the potential to revolutionize laboratory operations and bring significant advantages to healthcare providers and patients. However, careful consideration of challenges and implementation strategies is necessary to maximize the effectiveness of these systems [22, 23].

2.1. **Comparison with existing literature and identification of research gaps**

Existing literature on the automation of clinical laboratories generally supports the positive outcomes and benefits mentioned in their search findings. Many studies have shown that automation systems can improve efficiency, accuracy, and reliability of testing processes, leading to reduced turnaround times and improved quality of test results [1, 3, 5, 22]. However, there are still some research gaps that need to be addressed. Firstly, there is a requirement for more studies that specifically evaluate the cost-effectiveness of implementing automation systems in different types of clinical laboratories. While the initial investment maybe high, it is important to assess the long-term financial benefits and return on investment [23]. Secondly, further research is needed to explore the impact of automation on laboratory staff, including their job satisfaction, workload, and skill requirements.
Involved in the implementation of automation systems can help identify potential challenges and develop strategies to address them effectively. Additionally, more studies are needed to investigate the integration of automation systems with existing laboratory information management systems or electronic health record systems. This includes evaluating the compatibility of different systems, identifying barriers to integration and developing solutions to ensure seamless data management and reporting [10, 11, 23].

Furthermore, there is a lack of research on the long-term sustainability and scalability of automation systems in clinical laboratories. It would be valuable to explore how these systems can adapt and evolve over time to meet changing demands and advancements in technology [10, 11, 12, 13, 20]. In conclusion, while the existing literature supports the positive outcomes of implementing automation systems in clinical laboratories, there are still research gaps that need to be addressed. Future studies should focus on valuating the cost-effectiveness, impact on laboratory staff, integration with existing systems, and long-term sustainability of automation in clinical laboratories [21, 22].

![Figure 3](image)

**Figure 3.** Figure indicating the increment in percentage with respect to existing literature studies on automation impact

### 3. Conclusion

Henceforth after reviewing the scientific innovative automation technologies, it can be concluded that Laboratory automation significantly improves workflow efficiency in medical laboratories by streamlining processes, reducing errors, and enhancing productivity. The key findings include: Faster Turnaround Time: Automation technologies such as robotics, sample handling systems, and laboratory information management systems expedite specimen processing, analysis, and result reporting. This leads to shorter turnaround times for test results, enabling healthcare providers to make timely diagnoses and initiate appropriate treatments [22, 23]. In addition to that Automation minimizes manual handling and transcription errors, reducing the risk of mislabeling, sample mix-ups, and transcription mistakes and hence improves the accuracy and reliability of laboratory results, contributing to better...
patient care and treatment decisions. Automation in turn optimizes resource utilization, streamlines workflows, and eliminates redundant tasks. This enables laboratory personnel to handle a higher volume of tests efficiently, increasing overall productivity and capacity.

3.1. Improved Patient Care

Efficient workflows facilitated by automation technologies provide accurate and reliable test results promptly thereby enabling early detection, appropriate treatment planning, and effective disease management, ultimately improving patient outcomes and quality of care. It minimizes wastage of resources, reduces the probability of performing Retests due to manual errors, and optimizes equipment utilization. These factors greatly contribute to cost savings for medical laboratories and the healthcare system as a whole. Some of the noteworthy domains of Biotechnological principles including Diagnostics, Genomic Solutions, Microbiology, Drug Discovery and Proteomic Solutions have been extremely benefitted as a result of automation instrumentation and facilities as of the year 2023 [23].

3.2. Future research prospects on laboratory automation and workflow efficiency

Cost effectiveness studies should be conducted to evaluate the financial benefits and return on investment of implementing automation systems in different types of clinical laboratories. This will help decision-makers comprehend the economic impact and make informed decisions regarding adoption of laboratory automation. Furthermore, investigation of the effects of automation on job satisfaction, workload, and skill requirements of laboratory staff. Understanding the human factors involved in automation implementation can help address potential challenges and ensure a smooth transition for employees.

a. Explore integration with existing systems: Investigate the Compatibility issues and barriers to integrating automation systems with laboratory information management systems or electronic health record systems. This research can inform the development of solutions for seamless data management and reporting [9, 10, 12].

b. Investigate long-term sustainability and scalability: Study how automation systems can adapt and devolve overtime to meet changing demands and advancements in technology. This research will ensure the continued effectiveness and relevance of automation in clinical laboratory settings [12].

c. Evaluate the impact on patient outcomes: Assess how automation systems in clinical laboratories can improve patient care and outcomes. This research can provide evidence on the benefits of automation enhancing patient safety and quality of care.

d. Investigate potential challenges and barriers to implementation: Identify potential obstacles to implementing automation systems in clinical laboratories, such as regulatory requirements or resistance to change. This research can help develop strategies to overcome these challenges and ensure successful implementation.

e. Examine the impact on turnaround times and quality of test results: Evaluating the methodologies of automation systems can enhance efficiency, accuracy, and reliability of testing processes, leading to reduced turnaround times and improved quality of test results. This research will provide evidence on the positive outcomes of automation in clinical laboratory settings.
f. **Study the impact on workflow efficiency:** Investigate how automation systems can streamline laboratory workflows and optimize resource allocation. This research can provide insights into the benefits of automation in improving an overall efficiency.

g. **Explore the potential for collaboration and knowledge sharing:** Investigate how automation systems can facilitate collaboration and Knowledge sharing among diverse clinical laboratories. This research can provide insights into the potential benefits of automation in promoting best practices and improving overall laboratory performance.

h. **Conduct comparative studies:** Compare the outcomes and benefits of different automation systems in clinical laboratories to identify the most effective and efficient solutions. This research can inform decision-making regarding the selection and implementation of automation systems [23].

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**Declarations**

**Source of Funding**

This study did not receive any grant from funding agencies in the public or not-for-profit sectors.

**Competing Interests Statement**

The authors have declared no competing interests.

**Consent for Publication**

The authors declare that they consented to the publication of this study.

**Author’s Contribution**

All authors took part in data collection, literature review, analysis, and manuscript writing equally.

**References**


