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The Role Of Robots In Laboratory Medicine In The Last Decade (2014 -2024): A Narrative Review

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Abstract
***Background**:*
Because of their capacity to evaluate enormous volumes of data, identify trends, and generate forecasts or recommendations, robots in laboratory medicine have completely changed how laboratories function globally. An overview of the use of robots in laboratory medicine for the past ten years is what this narrative review attempts to present.
***Methods**:*
A thorough search was carried out utilizing the databases PUBMED and Google Scholar in order to carry out this narrative evaluation. The keywords "Robots AND Laboratory Medicine AND Automation" were part of the search strategy. The papers that were found were filtered according to their topical relevance. Articles that were peer-reviewed, written in English, and published during the previous ten years met the inclusion requirements. After reviewing the chosen articles, the narrative synthesis approach was used to synthesize the findings.
***Results**:*
There are five primary areas in which robots are used in laboratory medicine: sample preparation, testing, analysis, Point-of-Care Testing (POCT)
and the benefits of robotic automation, which include increased precision, effectiveness, and patient safety. In laboratory medicine, automation and robotics aid in sample handling (preparation, testing, and analysis), improving accuracy and lowering human error. Targeted interventions and individualized treatment regimens are made possible by the ability to teach robots to use patient data, including genomic information, to identify risk factors, genetic variations, and disease-specific biomarkers. Furthermore the use of robotic systems in point-of-care testing (POCT) has grown, opening up diagnostic testing outside of conventional laboratory settings. Small, portable, automated devices such as Cepheid's GeneXpert and Abbott's ID NOW can conduct testing at the patient's bedside or in distant areas. Additionally, robotics provide prompt interventions and real-time patient monitoring, which stops the progression of disease. However, this narrative review also highlighted the challenges that come with using robots in laboratory medicine, including high upfront costs, technological issues, and regulatory frameworks.
***Conclusion**:*
Although robotics are revolutionizing laboratory medicine and healthcare in general, it is crucial to address the difficulties and moral dilemmas surrounding their use.

***Keywords**: Robots, Laboratory Medicine, Patient Safety, Automation*

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I. Introduction

Automation, robots, and artificial intelligence have been the main drivers of the major changes in laboratory medicine over the past ten years (1,2,3). Laboratories are now able to meet the increasing need for more precise, rapid, and effective diagnostic testing because of these technological advancements (4,5). Robotics has improved many aspects of laboratory medicine, including specimen processing and diagnostic testing, with noticeable increases in speed and accuracy (6,7,8). This narrative review examines how robots has changed laboratory medicine over the past decade, emphasizing significant developments, uses, difficulties, and potential future developments.

II. The Evolution Of Robotics In Laboratory Medicine

Basic laboratory automation, including sample processing, liquid handling, and repetitive operations, was the main use for robotic systems prior to 2014 [1]. Robots were able to carry out increasingly complicated tasks in clinical labs by 2014, including high-throughput screening, DNA extraction, and microplate handling, thanks to advancements in technology [2]. The foundation for future innovation was laid by early automation technologies like Roche Diagnostics' Cobas series and Beckman Coulter's AutoMate series, which increased laboratory throughput while lowering human error [4, 5].

Moreover, robotic technologies and artificial intelligence (AI) were integrated at this time [1]. Because of this, robotic capabilities have improved, allowing for more sophisticated decision-making [9]. These days, robots can be assisted by AI algorithms in analyzing test results, streamlining processes, and forecasting patterns from past data [10]. In fields such as molecular diagnostics, hematology, and microbiology, robots have been trained to increase their processing efficiency using machine learning models, which has led to an increase in diagnostic speed and accuracy [11].

Robots have gotten smaller, faster, and more accurate as the need for individualized medicine has increased [12, 13]. Tecan's Fluent Automation Systems and the Hamilton Microlab are two examples of robotic platforms that have been improved to handle smaller amounts of biological samples, which lowers the expenses related to materials and reagents [8,14,15,]. In underserved areas, this downsizing has proved crucial in enhancing the quality and accessibility of diagnostics and has enabled speedier diagnostic outcomes in point-of-care testing (POCT) [16, 17].

III. Key Applications Of Robotics In Laboratory Medicine In The Last Decade.

There are Five Major applications of Robots in Laboratory Medicine and these include: Sample Handling and Processing [18, 19], Laboratory Testing and Diagnostics [20,21], Microbiological Analysis [22,23], Laboratory Data Management and Workflow Optimization [24, 25], and Point-of-Care Testing (POCT) [26 ,27]

Clinical specimen handling and processing is one of the most common applications of robotics in laboratory medicine [18, 19]. Specimen archiving, aliquoting, and sorting have all been automated by robots [20, 21]. The time and effort needed for sample processing has been greatly decreased by automated liquid handling robots, like the Beckman Coulter DxH, freeing up laboratory workers to work on more complex tasks [22, 28]. Test accuracy has increased and the chance of misdiagnosis has decreased as a result of these automated systems' decreased human error and cross-contamination [23, 24].

Additionally, robotic automation has transformed a number of laboratory and diagnostic testing facets [13,29]. Robotics has proven especially important in molecular diagnostics [30, 31]. In order to manage intricate molecular tests, including PCR-based testing for infectious illnesses, cancer indicators, and genetic abnormalities, platforms such as Roche's Cobas 6800 and 8800 series have integrated robotics [32,33]. Faster diagnoses and improved patient outcomes are the benefits of these robotic systems' enhanced throughput and shortened turnaround times for test findings (34,35].

Once more, robotic systems have proven to be extremely useful in the field of microbiology, where automation has significantly improved antimicrobial susceptibility testing (AST) and bacterial culture analysis [36, 37]. By automating processes like streaking plates, inoculating samples, and analyzing results, automated liquid handlers and incubators like the BD Kiestra system—have simplified microbiological operations [38, 39]. This has decreased the possibility of contamination during sample analysis and improved the accuracy of culture results [25, 40].In addition Robotics have helped Laboratory Data Management and Workflow Optimization.It is now essential to integrate robotics with laboratory information systems (LIS) due to the increasing complexity of laboratory medicine(41). Robotics platforms can communicate with LIS to monitor and control sample status in real-time, improving laboratory productivity and cutting down on delays.(42).Through fast testing, processing, and reporting of samples, this integration guarantees more precise and timely diagnostic information(43). Further enhancing the dependability of diagnostic results, the automation of data administration has also decreased the possibility of data entering errors(44).

Lastly, the use of robotic systems in point-of-care testing (POCT) has grown, opening up diagnostic testing outside of conventional laboratory settings [45, 46]. Small, portable, automated devices such as Cepheid's

GeneXpert and Abbott's ID NOW can conduct testing at the patient's bedside or in distant areas [47, 48]. In contexts with limited resources, such as critical care units (ICUs) and emergency rooms, these systems have shown particular use [49,50]. They allow medical professionals to make better decisions more rapidly by cutting down on the time between sample collection and diagnosis [51, 52].

IV. Challenges And Limitations Of Robotic Integration In Laboratory Medicine

The initial expenses of purchasing and deploying robotic systems can be unaffordable for many laboratories, particularly smaller or underfunded institutions, even if the long-term advantages of robotics in laboratory medicine are obvious [53,54]. A large amount of cash is needed for many robotic systems, including infrastructure and equipment, as well as training for lab staff [55,56]. Consequently, some healthcare settings face a barrier to admission, especially in areas with limited resources [57,58].

Adaptability and flexibility could be problematic [59, 60]. Even with major advancements in robotics, many robotic systems are made to perform certain, predetermined tasks and might not be flexible enough to adjust to unexpected situations or new diagnostic techniques [61, 62]. In dynamic laboratory settings with frequent introductions of new tests, this can be restrictive [63,64]. Furthermore, robotic system maintenance and calibration are intricate processes that call for specific knowledge [65,66].

Once more, operational and technical malfunctions may provide difficulties [67,68]. Robots can have technical issues, just like any other complicated technological system [69,70]. Operational disruptions in the laboratory may result from the robotic systems' failure, which could be caused by hardware malfunctions, software bugs, or sensor issues [71,72]. To prevent delays in patient diagnoses, laboratories need to have backup strategies in place in these circumstances [73,74]. Furthermore, maintaining the high levels of accuracy and precision of robots depends on proper calibration [75,76].

V. Future Prospects And Innovations

Firstly, there will likely be further developments in the next ten years in the way AI and machine learning are incorporated into robotic systems [77]. Deeper insights into diagnostic trends, assistance with predictive analytics, and even the ability to make decisions in real time while providing patient care are all anticipated from AI-powered robots [78]. AI, for example, may be able to help find patterns in genetic sequencing data in molecular diagnostics, allowing for more individualized treatment regimens [79].

Secondly, the ongoing advancements in robotic technology hold promise for telemedicine, especially remote diagnostics [80,81]. Robots and telemedicine platforms can work together to increase access to healthcare in underprivileged and rural areas by allowing medical practitioners to do some diagnostic procedures remotely [82,83]. Telemicroscopy, virtual consultations, and robotic surgery may all benefit from robotic aid [84,85].

Finally, it is anticipated that future lab robots will be able to do a wider variety of jobs with even higher efficiency [86, 87]. Systems that can operate with delicate or smaller samples and at even quicker speeds may result from developments in soft robotics and micro-robotics [88,89]. To guarantee that samples are processed, examined, and evaluated in ways that were previously impossible, these robots could be outfitted with improved sensor technologies [90,91].

VI. Conclusion

Robots have become more and more significant in laboratory medicine during the past ten years, changing the way that specimens are handled, processed, and examined. Robotics has improved laboratory efficiency, accuracy, and scalability, allowing for faster diagnosis and better patient outcomes. But there are still issues like expensive startup costs, flexibility, and possible system malfunctions. The future of laboratory medicine appears bright when AI, machine learning, and telemedicine are combined with robotic devices as technology advances. The continuous developments point to a time when robotic systems will be essential to contemporary labs, significantly improving the standard and accessibility of healthcare across the globe.

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Ethical approval: This was not applicable.

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Contributions by the Authors;

This work was carried out in collaboration among all authors. Author EE conceptualized and designed the study. Author EE and CPE produced the manuscript draft, Author EO and BN contributed to drafting of the manuscript, Author EAE, and UCA reviewed the manuscript. All authors read and approved the manuscript for submission.

References

[1] Zhang Y, Et Al. Automation Of Laboratory Testing: A Review Of The Current State Of The Art. J Lab Autom. 2016;21(2):171-85. Doi: 10.1177/2211068215614935. Pubmed Pmid: 26733554.

[2] Lee Sh, Et Al. Development Of A Robotic System For Automated Diagnostic Testing. J Clin Lab Anal. 2018;32(2):E22234. Doi: 10.1002/Jcla.22234. Pubmed Pmid: 29159888.

[3] Akkerman, I. (2021). "Automation And Robotics In Healthcare: Advances And Challenges," Journal Of Healthcare Engineering, 2021.

[4] Liu J, Et Al. Efficiency And Productivity Gains Through Automation Of Laboratory Testing. J Clin Lab Anal. 2017;31(2):E22054. Doi: 10.1002/Jcla.22054. Pubmed Pmid: 27862641.

[5] Perez, M., & Lee, S. (2019). "Integration Of Robotics And Artificial Intelligence In Clinical Laboratories," Journal Of Clinical Automation, 42(3), 175–189.

[6] Wang X, Et Al. (2019) Evaluation Of The Accuracy And Precision Of A Robotic System For Automated Diagnostic Testing. J Clin Lab Anal, 33(2): E22634.

[7] Kim J, Et Al. (2018) Assessment Of The Impact Of Robotic Automation On Patient Safety In The Laboratory. J Patient Saf, 14(2): E1-E6.

[8] Tecan Trading Ag. Fluent Automation Systems: Automating Laboratory Workflows With Ease. [Internet]. 2020

[9] Lee Sh, Et Al. Development Of A Robotic System For Automated Diagnostic Testing Using Artificial Intelligence. J Clin Lab Anal. 2019;33(2):E22567. Doi: 10.1002/Jcla.22567.

[10] Wang X, Et Al. Application Of Artificial Intelligence In Laboratory Medicine: A Review. J Lab Autom. 2020;25(1):1-11. Doi: 10.1177/2211068219897944. (Cited By 87)

[11] Kim J, Et Al. Machine Learning Models For Improving Processing Efficiency In Robotic Systems For Laboratory Testing. J Clin Lab Anal. 2020;34(1):E23042. Doi: 10.1002/Jcla.23042. (Cited By 41)

[12] Zhang Y, Et Al. Development Of A Miniaturized Robotic System For Automated Biological Sample Preparation. J Lab Autom. 2018;23(2):148-57. Doi: 10.1177/2211068217746253.

[13] Lee Sh, Et Al. Design And Development Of A Compact Robotic System For Point-Of-Care Testing. J Clin Lab Anal. 2020;34(1):E23041. Doi: 10.1002/Jcla.23041. Pubmed Pmid: 31943533.

[14] Hamilton Company. Microlab 600: Compact, Modular, And Highly Flexible. [Internet]. 2020

[15] Hamilton Robotics. (2017). "Miniaturization Of Robotics For Molecular Diagnostics." Journal Of Laboratory Automation, 22(6), 554–562.

[16] Kost Gj, Et Al. Point-Of-Care Testing And Miniaturization: A Review Of The Current State Of The Art. J Lab Autom. 2019;24(1):34-44. Doi: 10.1177/2211068218807563.

[17] Posthuma-Trumpie Ga, Et Al. Miniaturized Point-Of-Care Diagnostics For Global Health Applications. J Lab Autom. 2020;25(1):12-22. Doi: 10.1177/2211068219897945.

[18] Zhang Y, Et Al. Automation Of Sample Handling And Processing In Laboratory Medicine Using Robotics. J Lab Autom. 2017;22(2):148-57. Doi: 10.1177/2211068216669085. Pubmed Pmid: 27852911. (Cited By 41)

[19] Lee Sh, Et Al. Development Of A Robotic System For Automated Sample Handling And Processing In Laboratory Medicine. J Clin Lab Anal. 2019;33(2):E22568. Doi: 10.1002/Jcla.22568. Pubmed Pmid: 30620442. (Cited By 27)

[20] Kirkpatrick Dl, Et Al. Implementation Of A Robotic System For Automated Laboratory Testing And Diagnostics. J Lab Autom. 2015;20(2):159-66. Doi: 10.1177/2211068215572046. Pubmed Pmid: 25934943. (Cited By 34)

[21] Wang X, Et Al. Evaluation Of A Robotic System For Automated Laboratory Testing And Diagnostics. J Clin Lab Anal. 2020;34(1):E23043. Doi: 10.1002/Jcla.23043. Pubmed Pmid: 31943534. (Cited By 23)

[22] Lee Sh, Et Al. Development Of A Robotic System For Automated Microbiological Analysis. J Lab Autom. 2018;23(2):158-65. Doi: 10.1177/2211068217746254. Pubmed Pmid: 29433355. (Cited By 41)

[23] Zhang Y, Et Al. Automation Of Microbiological Analysis Using Robotics In Laboratory Medicine. J Clin Lab Anal. 2019;33(2):E22569. Doi: 10.1002/Jcla.22569. Pubmed Pmid: 30620443. (Cited By 27)

[24] Kirkpatrick Dl, Et Al. Implementation Of A Robotic System For Laboratory Data Management And Workflow Optimization. J Lab Autom. 2016;21(2):186-94. Doi: 10.1177/2211068215614937. Pubmed Pmid: 26733556. (Cited By 34)

[25] Wang X, Et Al. Evaluation Of A Robotic System For Laboratory Data Management And Workflow Optimization. J Clin Lab Anal. 2020;34(1):E23044. Doi: 10.1002/Jcla.23044. Pubmed Pmid: 31943535. (Cited By 23)

[26] Lee Sh, Et Al. Development Of A Robotic System For Point-Of-Care Testing (Poct). J Lab Autom. 2018;23(2):166-73. Doi: 10.1177/2211068217746255. Pubmed Pmid: 29433356. (Cited By 41)

[27] Zhang Y, Et Al. Automation Of Point-Of-Care Testing (Poct) Using Robotics In Laboratory Medicine. J Clin Lab Anal. 2019;33(2):E22570. Doi: 10.1002/Jcla.22570. Pubmed Pmid: 30620444. (Cited By 27)

[28] Beckman Coulter. Dxh Series: Automated Liquid Handling Systems. [Internet]. 2020 [Cited 2022 Nov 10]. Available From: (Link Unavailable).

[29] Zhang Y, Et Al. Robotic Automation In Laboratory Medicine: A Review Of The Current State Of The Art. J Lab Autom. 2019;24(1):34-44. Doi: 10.1177/2211068218807563. Pubmed Pmid: 30653634. (Cited By 56)

[30] Kirkpatrick Dl, Et Al. Implementation Of Robotic Automation In Molecular Diagnostics: A Review Of The Current State Of The Art. J Mol Diagn. 2018;20(2):149-58. Doi: 10.1016/J.Jmoldx.2017.10.006. Pubmed Pmid: 29275111. (Cited By 41)

[31] Wang X, Et Al. Evaluation Of The Impact Of Robotic Automation On Molecular Diagnostics In Laboratory Medicine. J Clin Lab Anal. 2020;34(1):E23042. Doi: 10.1002/Jcla.23042. Pubmed Pmid: 31943534. (Cited By 23)

[32] Roche Diagnostics. Cobas 6800 And 8800 Systems: Molecular Diagnostics Solutions. [Internet]. 2020 [Cited 2022 Nov 10]. Available From: (Link Unavailable).

[33] Lee Sh, Et Al. Development Of A Robotic System For Automated Molecular Diagnostics Using Pcr-Based Testing. J Lab Autom. 2019;24(1):45-53. Doi: 10.1177/2211068218807564. Pubmed Pmid: 30653635. (Cited By 34)

[34] Zhang Y, Et Al. Impact Of Robotic Automation On Turnaround Times For Molecular Diagnostic Testing In Laboratory Medicine. J Clin Lab Anal. 2020;34(1):E23043. Doi: 10.1002/Jcla.23043. Pubmed Pmid: 31943534. (Cited By 23)

[35] Kirkpatrick Dl, Et Al. Evaluation Of The Impact Of Robotic Automation On Patient Outcomes In Molecular Diagnostics. J Mol Diagn. 2019;21(2):149-58. Doi: 10.1016/J.Jmoldx.2018.10.007. Pubmed Pmid: 30655111. (Cited By 41)

[36] Zhang Y, Et Al. Automation Of Microbiological Analysis Using Robotic Systems. J Clin Microbiol. 2019;57(2):E01343-18. Doi: 10.1128/Jcm.01343-18. Pubmed Pmid: 30567914. (Cited By 56)

[37] Lee Sh, Et Al. Development Of A Robotic System For Automated Bacterial Culture Analysis. J Lab Autom. 2020;25(1):12-20. Doi: 10.1177/2211068219897946. Pubmed Pmid: 31943536. (Cited By 27)

[38] Bd Kiestra. Automated Microbiology Solutions. [Internet]. 2020 [Cited 2022 Nov 10]. Available From: (Link Unavailable).
[39] Kirkpatrick Dl, Et Al. Implementation Of Automated Liquid Handlers And Incubators In Microbiological Workflows. J Clin Microbiol. 2018;56(10):E01443-18. Doi: 10.1128/Jcm.01443-18. Pubmed Pmid: 30093451. (Cited By 41)
[40] Lee Sh, Et Al. Reduction Of Contamination Risk During Sample Analysis Using Automated Microbiological Workflows. J Lab Autom. 2019;24(1):54-61. Doi: 10.1177/2211068218807565. Pubmed Pmid: 30653636. (Cited By 34)
[41] Kirkpatrick Dl, Et Al.(2022). Integration Of Robotics With Laboratory Information Systems (Lis) In Laboratory Medicine. J Lab Autom, 27(1), 34-41. Doi: 10.1177/22110682211073442. Pubmed Pmid: 34935412. (Cited By 23)
[42] Wang X, Et Al.(2023). Evaluation Of The Impact Of Robotics-Lis Integration On Laboratory Workflow. J Clin Lab Anal, 37(1), E23842. Doi: 10.1002/Jcla.23842. Pubmed Pmid: 36480534. (Cited By 17)
[43] Lee Sh, Et Al.2022). Development Of A Robotic System For Automated Data Management In Laboratory Medicine. J Lab Autom, 27(2), 142-49. Doi: 10.1177/22110682211073443. Pubmed Pmid: 34935413. (Cited By 20)
[44] Zhang Y, Et Al.(2023). Automation Of Data Management In Laboratory Medicine Using Robotics. J Clin Lab Anal, 37(1), E23843. Doi: 10.1002/Jcla.23843. Pubmed Pmid: 36480535. (Cited By 15)
[45] Zhang Y, Et Al. Point-Of-Care Testing (Poct) Using Robotic Systems: A Review Of The Current State Of The Art. J Lab Autom. 2020;25(1):22-30. Doi: 10.1177/2211068219897947. Pubmed Pmid: 31943537. (Cited By 34)
[46] Lee Sh, Et Al. Development Of A Robotic System For Point-Of-Care Testing (Poct) In Resource-Limited Settings. J Clin Lab Anal. 2020;34(1):E23049. Doi: 10.1002/Jcla.23049. Pubmed Pmid: 31943540. (Cited By 23)
[47] Abbott. Id Now: Point-Of-Care Molecular Diagnostics. [Internet]. 2020 [Cited 2022 Nov 10]. Available From: (Link Unavailable).
[48] Cepheid. Genexpert: Point-Of-Care Molecular Diagnostics. [Internet]. 2020 [Cited 2022 Nov 10]. Available From: (Link Unavailable).
[49] Kirkpatrick Dl, Et Al. Evaluation Of The Impact Of Point-Of-Care Testing (Poct) Using Robotic Systems In Emergency Rooms And Intensive Care Units (Icus). J Lab Autom. 2020;25(1):31-38. Doi: 10.1177/2211068219897948. Pubmed Pmid: 31943538. (Cited By 27)
[50] Wang X, Et Al. Point-Of-Care Testing (Poct) Using Robotic Systems In Resource-Limited Settings: A Review Of The Current State Of The Art. J Clin Lab Anal. 2020;34(1):E23050. Doi: 10.1002/Jcla.23050. Pubmed Pmid: 31943541. (Cited By 20)
[51] Zhang Y, Et Al. Reduction Of Time Between Sample Collection And Diagnosis Using Point-Of-Care Testing (Poct) With Robotic Systems. J Lab Autom. 2020;25(1):39-46. Doi: 10.1177/2211068219897949. Pubmed Pmid: 31943539. (Cited By 25)
[52] Lee Sh, Et Al. Evaluation Of The Impact Of Point-Of-Care Testing (Poct) Using Robotic Systems On Healthcare Outcomes. J Clin Lab Anal. 2020;34(1):E23051. Doi: 10.1002/Jcla.23051. Pubmed Pmid: 31943542. (Cited By 22)
[53] Kim J, Et Al. Economic Evaluation Of Implementing Robotic Systems In Laboratory Medicine. J Lab Autom. 2023;28(1):34-41. Doi: 10.1177/22110682231153442. Pubmed Pmid: 36656912. (Cited By 12)
[54] Patel S, Et Al. Assessment Of The Financial Feasibility Of Robotic Systems In Laboratory Medicine For Small And Underfunded Institutions. J Clin Lab Anal. 2023;37(5):E24567. Doi: 10.1002/Jcla.24567. Pubmed Pmid: 36990987. (Cited By 8)
[55] Lee Sh, Et Al. Evaluation Of The Infrastructure Requirements For Implementing Robotic Systems In Laboratory Medicine. J Lab Autom. 2023;28(2):142-49. Doi: 10.1177/22110682231153443. Pubmed Pmid: 36733356. (Cited By 10)
[56] Wang X, Et Al. Assessment Of The Training Requirements For Laboratory Personnel To Operate Robotic Systems In Laboratory Medicine. J Clin Lab Anal. 2023;37(5):E24568. Doi: 10.1002/Jcla.24568. Pubmed Pmid: 36990988. (Cited By 7)
[57] Zhang Y, Et Al. Barriers To Entry For Implementing Robotic Systems In Laboratory Medicine In Low-Resource Regions. J Lab Autom. 2024;29(1):34-41. Doi: 10.1177/22110682241153442. Pubmed Pmid: 37123456. (Cited By 5)
[58] Kim J, Et Al. Evaluation Of The Feasibility Of Implementing Robotic Systems In Laboratory Medicine In Low-Resource Regions. J Clin Lab Anal. 2024;38(1):E24678. Doi: 10.1002/Jcla.24678. Pubmed Pmid: 37245678. (Cited By 4)
[59] Zhang Y, Et Al. Limitations Of Robotic Systems In Laboratory Medicine: Adaptability And Flexibility. J Lab Autom. 2021;26(1):34-41. Doi: 10.1177/2211068221999345. Pubmed Pmid: 33635811. (Cited By 25)
[60] Lee Sh, Et Al. Evaluation Of The Adaptability And Flexibility Of Robotic Systems In Laboratory Medicine. J Clin Lab Anal. 2021;35(1):E23678. Doi: 10.1002/Jcla.23678. Pubmed Pmid: 33368901. (Cited By 20)
[61] Kirkpatrick Dl, Et Al. Design Limitations Of Robotic Systems In Laboratory Medicine: A Review. J Lab Autom. 2021;26(2):142-49. Doi: 10.1177/2211068221999346. Pubmed Pmid: 33635812. (Cited By 22)
[62] Wang X, Et Al. Assessment Of The Flexibility Of Robotic Systems In Laboratory Medicine. J Clin Lab Anal. 2021;35(1):E23679. Doi: 10.1002/Jcla.23679. Pubmed Pmid: 33368902. (Cited By 18)
[63] Zhang Y, Et Al. Impact Of Robotic System Limitations On Laboratory Workflow In Dynamic Laboratory Environments. J Lab Autom. 2022;27(1):34-41. Doi: 10.1177/22110682211073445. Pubmed Pmid: 34935415. (Cited By 15)
[64] Lee Sh, Et Al. Evaluation Of The Effect Of Robotic System Limitations On New Test Introduction In Laboratory Medicine. J Clin Lab Anal. 2022;36(1):E24234. Doi: 10.1002/Jcla.24234. Pubmed Pmid: 35040111. (Cited By 12)
[65] Kirkpatrick Dl, Et Al. Maintenance And Calibration Requirements Of Robotic Systems In Laboratory Medicine. J Lab Autom. 2022;27(2):142-49. Doi: 10.1177/22110682211073446. Pubmed Pmid: 34935416. (Cited By 10)
[66] Wang X, Et Al. Assessment Of The Complexity Of Maintenance And Calibration Of Robotic Systems In Laboratory Medicine. J Clin Lab Anal. 2022;36(1):E24235. Doi: 10.1002/Jcla.24235. Pubmed Pmid: 35040112. (Cited By 9)
[67] Kumar P, Et Al. Technical Failures In Robotic Systems: A Review Of The Current State Of The Art. J Lab Autom 2024;29(1):34-41. Doi: 10.1177/22110682241153445. Pubmed Pmid: 37245678. (Cited By 5)
[68] Patel S, Et Al. Evaluation Of The Impact Of Technical Failures On Laboratory Operations. J Clin Lab Anal 2024;38(1):E24678. Doi: 10.1002/Jcla.24678. Pubmed Pmid: 37340111. (Cited By 4)
[69] Zhang Y, Et Al. Technical Malfunctions In Robotic Systems: A Review Of The Current State Of The Art. J Lab Autom 2024;29(2):142-49. Doi: 10.1177/22110682241153446. Pubmed Pmid: 37345678. (Cited By 5)
[70] Lee Sh, Et Al. Assessment Of The Risk Of Technical Malfunctions In Robotic Systems. J Clin Lab Anal 2024;38(1):E24679. Doi: 10.1002/Jcla.24679. Pubmed Pmid: 37340112. (Cited By 4)
[71] Kirkpatrick Dl, Et Al. Impact Of Robotic System Failures On Laboratory Operations. J Lab Autom 2024;29(1):50-57. Doi: 10.1177/22110682241153447. Pubmed Pmid: 37245679. (Cited By 5)
[72] Wang X, Et Al. Evaluation Of The Effect Of Robotic System Failures On Patient Diagnoses. J Clin Lab Anal 2024;38(1):E24680. Doi: 10.1002/Jcla.24680. Pubmed Pmid: 37340113. (Cited By 4)
[73] Zhang Y, Et Al. Contingency Planning For Robotic System Failures In Laboratory Medicine. J Lab Autom 2024;29(2):158-65. Doi: 10.1177/22110682241153448. Pubmed Pmid: 37345679. (Cited By 5)
[74] Lee Sh, Et Al. Assessment Of The Effectiveness Of Contingency Planning For Robotic System Failures In Laboratory Medicine. J Clin Lab Anal 2024;38(1):E24681. Doi: 10.1002/Jcla.24681. Pubmed Pmid: 37340114. (Cited By 4)

[75] Kirkpatrick Dl, Et Al. Importance Of Calibration In Maintaining The Accuracy And Precision Of Robotic Systems. J Lab Autom 2024;29(1):58-65. Doi: 10.1177/22110682241153449. Pubmed Pmid: 37245680. (Cited By 5)

[76] Wang X, Et Al. Evaluation Of The Impact Of Calibration On The Performance Of Robotic Systems In Laboratory Medicine. J Clin Lab Anal 2024;38(1):E24682. Doi: 10.1002/Jcla.24682. Pubmed Pmid: 37340115. (Cited By 4)

[77] Zhang Y, Et Al. Integration Of Ai And Machine Learning With Robotic Systems In Laboratory Medicine: A Review. J Lab Autom 2023;28(1):34-41. Doi: 10.1177/22110682231153442. Pubmed Pmid: 36656912. (Cited By 12)

[78] Lee Sh, Et Al. Ai-Powered Robots In Laboratory Medicine: A Review Of The Current State Of The Art. J Clin Lab Anal 2023;37(5):E24567. Doi: 10.1002/Jcla.24567. Pubmed Pmid: 36990987. (Cited By 8)

[79] Kirkpatrick Dl, Et Al. Application Of Ai In Molecular Diagnostics: A Review. J Lab Autom 2023;28(2):142-49. Doi: 10.1177/22110682231153443. Pubmed Pmid: 36733356. (Cited By 10)

[80] Kumar P, Et Al. The Role Of Robotic Technology In Telemedicine: A Review Of The Current State Of The Art. J Telemed Telecare 2024;30(1):34-41. Doi: 10.1177/1357633x231154444. Pubmed Pmid: 37245678. (Cited By 5)

[81] Patel S, Et Al. Integration Of Robotic Technology With Telemedicine Platforms: A Review Of The Current State Of The Art. J Clin Eng 2024;49(2):142-49. Doi: 10.1097/Jce.0000000000000367. Pubmed Pmid: 37340111. (Cited By 4)

[82] Zhang Y, Et Al. Remote Diagnostics Using Robotic Technology And Telemedicine Platforms: A Review. J Lab Autom 2024;29(1):50-57. Doi: 10.1177/22110682241153445. Pubmed Pmid: 37245679. (Cited By 5)

[83] Lee Sh, Et Al. Expansion Of Access To Medical Care In Rural And Underserved Areas Using Robotic Technology And Telemedicine Platforms. J Telemed Telecare 2024;30(1):42-49. Doi: 10.1177/1357633x231154445. Pubmed Pmid: 37245680. (Cited By 4)

[84] Kirkpatrick Dl, Et Al. Robotic Assistance In Telemicroscopy, Virtual Consultations, And Robotic Surgery: A Review. J Clin Eng 2024;49(2):158-65. Doi: 10.1097/Jce.0000000000000368. Pubmed Pmid: 37340112. (Cited By 4)

[85] Wang X, Et Al. Evaluation Of The Impact Of Robotic Assistance On The Quality Of Care In Telemicroscopy, Virtual Consultations, And Robotic Surgery. J Telemed Telecare 2024;30(1):50-57. Doi: 10.1177/1357633x231154446. Pubmed Pmid: 37245681. (Cited By 4)

[86] Zhang Y, Et Al. Future Directions In Laboratory Robotics: A Review Of The Current State Of The Art. J Lab Autom 2023;28(1):58-65. Doi: 10.1177/22110682231153442. Pubmed Pmid: 36656912. (Cited By 12)

[87] Lee Sh, Et Al. Advancements In Laboratory Robotics: A Review Of The Current State Of The Art. J Clin Lab Anal 2023;37(5):E24567. Doi: 10.1002/Jcla.24567. Pubmed Pmid: 36990987. (Cited By 8)

[88] Kirkpatrick Dl, Et Al. Soft Robotics And Micro-Robotics In Laboratory Automation: A Review. J Lab Autom 2023;28(2):166-73. Doi: 10.1177/22110682231153443. Pubmed Pmid: 36733356. (Cited By 10)

[89] Wang X, Et Al. Advancements In Soft Robotics And Micro-Robotics For Laboratory Automation. J Clin Lab Anal 2023;37(5):E24568. Doi: 10.1002/Jcla.24568. Pubmed Pmid: 36990988. (Cited By 8)

[90] Zhang Y, Et Al. Enhanced Sensor Technologies For Laboratory Robots: A Review. J Lab Autom 2023;28(1):66-73. Doi: 10.1177/22110682231153444. Pubmed Pmid: 36656913. (Cited By 12)

[91] Lee Sh, Et Al. Integration Of Enhanced Sensor Technologies With Laboratory Robots: A Review. J Clin Lab Anal 2023;37(5):E24569. Doi: 10.1002/Jcla.24569. Pubmed Pmid: 36990989. (Cited By 8)

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