Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

COMPARATIVE REVIEW OF MANUAL HEMATOLOGICAL METHODS AND EMERGING TECHNOLOGIES IN HEMATOLOGY DIAGNOSTICS

Raza
Investigator, FAHS Department of Medical Laboratory Technology Superior University Lahore
Dr. Rida Fatima
Principal Investigator, FAHS Department of Medical Laboratory Technology Superior University Lahore
rida.fatima@superior.edu.pk
Sidra Iqbal
Head of department medical lab technology, FAHS Department of Medical Laboratory Technology Superior University Lahore
Ijaz Ahmad
Program leader medical lab technology, FAHS Department of Medical Laboratory Technology Superior University Lahore

Author Details

Keywords:
Hematology, manual methods, flow cytometry, digital imaging, peripheral blood smear, immunophenotyping, laboratory diagnostics, automation

Received on 10 Mar 2026
Accepted on 22 Apr 2026
Published on 09 May 2026

Corresponding E-mails & Authors*:
Raza

Abstract

Background: Hematological diagnostics has evolved substantially with the introduction of advanced diagnostic technologies. Conventional manual methods, such as peripheral blood smear examination and cytochemical staining, have long served as the foundation of hematological diagnosis by allowing direct assessment of blood cell morphology. In recent years, these traditional approaches have increasingly been supported by newer technologies such as flow cytometry, digital imaging, and automated hematology analyzers, which offer improved accuracy, speed, standardization, and reproducibility.

Objective: This review aims to compare conventional manual hematological methods with emerging technologies, particularly flow cytometry and digital imaging, with respect to diagnostic performance, efficiency, reproducibility, and clinical utility.

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

Methodology: A narrative review was carried out using peer-reviewed research articles, textbooks, and clinical guidelines retrieved from Google Scholar, PubMed, ScienceDirect, and PubMed Central. Literature published between January 2000 and December 2024 was reviewed (search conducted March 2026). The initial search yielded 847 articles; after title/abstract screening, 124 full-text articles were assessed, and 62 studies met inclusion criteria. No formal quality assessment tool was used, consistent with narrative review methodology. The author acknowledges that narrative reviews are hypothesis-generating rather than systematic.

Results: Manual hematological methods remain valuable for detailed morphological assessment and for identifying rare or abnormal cells that may be overlooked by automated systems. Still, they are labor-intensive, time-consuming, and prone to observer variability. For example, Katz et al. (2022) reported that remote digital microscopy reduced peripheral blood smear turnaround time by 32%. Flow cytometry provides rapid, sensitive, and multiparametric analysis, making it indispensable for immunophenotyping, leukemia classification, and disease monitoring. Digital imaging enhances standardization, improves workflow, and allows automated cell recognition as well as remote consultation. Automated hematology analyzers have improved routine testing efficiency, though they still require manual confirmation in abnormal or flagged cases. Despite their advantages, advanced technologies are costly and require skilled personnel, technical expertise, and laboratory infrastructure.

Conclusion: Emerging technologies such as flow cytometry and digital imaging have greatly strengthened hematological diagnostics by improving accuracy, speed, and consistency. Nevertheless, manual methods continue to play an important complementary role, especially in complex, doubtful, or morphology-dependent cases. The most effective approach in modern hematology is an integrated one that combines traditional expertise with advanced technology to achieve better diagnosis and patient management.

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

INTRODUCTION

Hematology is a branch of laboratory medicine concerned with the study of blood, blood-forming tissues, and disorders affecting these systems. It plays a central role in the diagnosis, classification, and monitoring of a wide range of clinical conditions, including anemia, infection, inflammatory disorders, bleeding disorders, and hematological malignancies. Accurate hematological investigation is essential for sound clinical decision-making and effective patient care. Over time, hematology has evolved from purely morphology-based assessment to technologically advanced, data-driven diagnostics, reflecting the growing demand for speed, precision, and consistency in laboratory practice.

Traditionally, hematological analysis has relied heavily on manual examination, particularly peripheral blood smear review under the microscope. This technique allows direct visualization of blood cell morphology and provides valuable information regarding the size, shape, staining characteristics, and maturity of red blood cells, white blood cells, and platelets. Manual smear examination remains one of the most informative methods for detecting subtle morphological abnormalities such as anisocytosis, poikilocytosis, toxic granulation, blast cells, and platelet clumping, which are often crucial for diagnosis.

Despite its diagnostic value, manual microscopy has important limitations. It is labor-intensive and time-consuming, and highly dependent on the skill and experience of the observer. Differences in training and interpretation can result in inter-observer and intra-observer variability, affecting standardization and reproducibility. In addition, manual techniques are not ideal for laboratories with large workloads, where rapid turnaround time and high-throughput processing are required.

To address these challenges, hematology laboratories have increasingly adopted automated and advanced diagnostic technologies. Automated hematology analyzers have improved the speed and precision of complete blood counts and differentials. Flow cytometry has become a key tool for immunophenotyping and detailed cellular analysis, particularly in leukemia and lymphoma. Digital imaging systems now provide automated slide scanning, cell preclassification, and telehematology

Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20120048

support. These technologies have improved efficiency and standardization, but they have not eliminated the need for manual review. In many clinical settings, the most reliable approach remains one in which advanced technology and expert human interpretation are used together.

PROBLEM STATEMENT

Hematological diagnosis has traditionally relied on manual methods such as peripheral blood smear examination and light microscopy. These methods provide detailed morphological information, but they require considerable time and expertise, and their accuracy depends greatly on the observer's skill. This often leads to variability in interpretation and limited standardization. Recent advances, including flow cytometry, digital imaging, and automation, have improved diagnostic speed, sensitivity, and consistency. Yet these methods are often expensive and demand specialized equipment, technical expertise, and suitable infrastructure, which limits their accessibility, especially in developing settings. At the same time, manual methods remain essential for detecting subtle abnormalities that automated systems may miss. No published consensus exists on optimal integration strategies for traditional and advanced methods in routine hematology practice. A comparative review of these approaches is therefore needed to clarify their strengths, weaknesses, and appropriate clinical roles.

OPERATIONAL DEFINITIONS (Alphabetized)

Automated Hematology Analyzer: A laboratory instrument that automatically counts and characterizes blood cells, including red blood cells, white blood cells, and platelets, using techniques such as electrical impedance, optical detection, and flow-based principles, and provides complete blood count parameters with minimal manual intervention.

Digital Imaging: A computer-assisted technique in hematology that captures and analyzes microscopic images of blood cells on prepared slides. It supports automated cell identification, classification, documentation, and remote review with improved speed and consistency.

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

Flow Cytometry: A laser-based technology that analyzes individual cells using light scatter and fluorescently labeled antibodies to identify cell size, internal complexity, and antigen expression. It is widely used for immunophenotyping, leukemia classification, and disease monitoring.

Manual Hematology Methods: Traditional laboratory methods in which trained personnel examine blood smears microscopically for white blood cell differential count, red blood cell morphology, platelet estimation, and detection of abnormal cells.

MATERIALS AND METHODS

Study Design: This study is a narrative review conducted to compare traditional manual hematological methods with modern diagnostic technologies, particularly flow cytometry and digital imaging, in hematology practice. The author acknowledges that narrative reviews are hypothesis-generating rather than systematic, and no formal quality assessment tool was applied to included studies.

Data Sources: Relevant literature was obtained from recognized electronic databases, including Google Scholar, PubMed, ScienceDirect, and PubMed Central.

Search Strategy: The literature search was performed using combinations of the following terms: Hematology diagnostics, Manual methods in hematology, Peripheral blood smear, Flow cytometry, Digital imaging in hematology, Automated hematology analyzers, Immunophenotyping. Boolean operators such as AND and OR were used to refine the search process. The search was conducted in March 2026, covering literature published between January 2000 and December 2024.

Search Results: The initial search yielded 847 articles. After removing duplicates (n=203), 644 titles and abstracts were screened. Full-text review was performed for 124 articles, of which 62 met inclusion criteria.

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

Inclusion Criteria:

- Articles published in English
- Studies published between 2000 and 2024
- Peer-reviewed original articles, review articles, textbooks, and clinical guidelines
- Studies comparing manual methods with flow cytometry and/or digital imaging
- Studies focusing on diagnostic accuracy, efficiency, reproducibility, and clinical applications

Exclusion Criteria:

- Case reports, editorials, and non-peer-reviewed articles
- Studies unrelated to hematology diagnostics
- Duplicate or incomplete studies
- Articles focused on unrelated laboratory methods

Data Analysis: I reviewed selected studies and analyzed them comparatively according to key parameters, including diagnostic accuracy, efficiency, reproducibility, and clinical utility.

RESULTS

The reviewed literature showed that manual hematological methods, automated hematology analyzers, flow cytometry, and digital imaging each contribute differently to hematology diagnostics.

Manual Methods: Manual peripheral blood smear examination remained the most informative method for direct morphological assessment. In a 2023 consensus recommendation by Chase et al., manual review was deemed essential for detecting abnormal red cell morphology, atypical leukocytes, blast forms, and platelet clumping. Comar et al. (2017) reported that 18.5% of automated complete blood counts required manual smear confirmation in a large university hospital setting.

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

Automated Analyzers: Gulati et al. (2022) documented that automated analyzers achieve high precision for routine parameters but generate false-positive flags in up to 15-20% of abnormal specimens. Furundarena et al. (2017) compared Sysmex XN and Beckman Coulter DxH 800 flagging performance, finding that both systems required smear review for confirmation of blasts and immature granulocytes.

Flow Cytometry: Brown & Wittwer (2000) established flow cytometry's sensitivity for detecting minimal residual disease down to 0.01%. Kumar et al.'s 2025 systematic review (in press) reported that flow cytometry has a pooled sensitivity of 94% for leukemia immunophenotyping compared to cytochemistry.

Digital Imaging: Katz et al. (2022) demonstrated that remote digital microscopy reduced peripheral blood smear turnaround time from 48 minutes to 33 minutes (32% reduction). The ICSH review by Kratz et al. (2019) noted that digital morphology analyzers achieved 85-90% concordance with manual review for normal cells, but concordance dropped to 60-70% for abnormal cells.

Comparative Summary: The table below summarizes key quantitative comparisons derived from the reviewed literature.

Parameter	Manual	Automated Analyzer	Flow Cytometry	Digital Imaging
Sensitivity for blast detection	~85-90% (observer-dependent)	~70-80% (flagging)	~95-99% (with appropriate panels)	~75-85% (preclassification)

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

Parameter	Manual	Automated Analyzer	Flow Cytometry	Digital Imaging
Turnaround time (routine CBC with differential)	20-30 min (expert)	1-2 min	2-4 hours (sample preparation)	5-10 min (scan + verification)
Inter-observer agreement (kappa)	0.65-0.80 (variable)	N/A (standardized)	0.90-0.95 (gating protocols)	0.80-0.90 (preclassified images)

Note: Values are synthesized from references 7, 9, 10, 12, 16, 17, 24, 27,32 and 38.

Overall, the literature did not support complete replacement of one method by another. Instead, the findings favored an integrated diagnostic model: automated analyzers support rapid routine screening, manual smear review provides morphological confirmation, flow cytometry offers immunophenotypic and multiparametric characterization, and digital imaging strengthens standardization and workflow.

A range of sources including textbooks, reviews, guidelines, and selected original studies was examined to compare the diagnostic role, efficiency, reproducibility, and clinical utility of manual hematological methods, automated analyzers, flow cytometry, and digital imaging in routine and specialized hematology practice.

DISCUSSION

This review highlights the ongoing transition in hematological diagnostics from conventional morphology-based techniques to more automated and technology-driven methods. The literature

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

examined suggests that modern diagnostic tools have improved speed, consistency, and analytical depth. Yet they have not made manual methods obsolete. Rather, the available evidence supports a complementary model in which traditional expertise and new technologies work together to provide the most accurate and clinically meaningful results.

Manual Methods in Hematology

Manual methods, especially peripheral blood smear examination, remain among the most informative components of hematological assessment. Through direct microscopic observation, trained personnel can identify subtle yet diagnostically important features such as anisocytosis, poikilocytosis, polychromasia, toxic granulation, Döhle bodies, blast forms, schistocytes, target cells, platelet clumping, and atypical lymphocytes. These findings are often essential in the diagnosis of anemia, hemolytic states, infections, leukemias, and other hematological disorders.

The main strength of manual examination lies in morphological interpretation. While automated instruments generate numerical data and abnormal flags, manual review provides context and pattern recognition. This is especially important when rare or unexpected cell populations are present, or when abnormal findings need confirmation. Manual microscopy is also valuable in cases where automated analyzers produce uncertain results or where instrument limitations reduce diagnostic confidence.

Even so, manual methods have clear disadvantages. They are time-consuming and labor-intensive, making them less suitable for laboratories with heavy workloads. Accuracy depends heavily on training, experience, and attention to detail. Because interpretation varies among observers, consistency can be difficult to maintain. These limitations reduce efficiency and standardization in routine practice, particularly in high-volume centers.

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

Automated Hematology Analyzers

The introduction of automated hematology analyzers represented a major advance in laboratory efficiency. These instruments allow rapid processing of large numbers of samples and provide accurate quantitative measurements such as hemoglobin concentration, red cell indices, platelet count, and white cell count. They reduce turnaround time, improve workflow, and minimize some forms of human error.

Automated analyzers are especially useful in routine screening and monitoring, where large numbers of samples must be processed quickly and consistently. Their ability to generate standardized data makes them essential in modern laboratories. They also provide flagging systems that alert laboratory staff to potential abnormalities requiring further investigation.

Still, automation has limitations. Automated systems may fail to identify abnormal morphology accurately, especially when immature, dysplastic, fragmented, or uncommon cells are present. In such circumstances, false-positive and false-negative flags may occur, requiring confirmatory smear review. This shows that automation improves routine hematology practice but does not replace expert interpretation.

Role of Flow Cytometry

Flow cytometry has become one of the most important tools in modern hematology. It provides rapid and multiparametric analysis of individual cells by measuring light scatter properties and fluorescence emitted from labeled antibodies. This allows precise immunophenotypic characterization of cell populations and has made flow cytometry indispensable in the diagnosis and classification of hematological malignancies.

Its primary applications include leukemia and lymphoma immunophenotyping, detection of abnormal or clonal cell populations, monitoring of treatment response, and identification of minimal residual disease. The sensitivity of flow cytometry makes it particularly useful in cases where

Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20120048

morphological examination alone is insufficient. It also supports subclassification of disease, which is increasingly important for prognosis and treatment planning.

Despite these advantages, flow cytometry is not a complete substitute for other diagnostic methods. It does not provide the same detailed morphological picture as microscopic examination, and its interpretation depends on appropriate antibody panels, technical expertise, and clinical correlation. In addition, its cost and infrastructure requirements may limit accessibility in resource-constrained settings. Therefore, flow cytometry is best viewed as a high-value complementary technique, especially in complex and malignant hematological disorders.

Role of Digital Imaging

Digital imaging systems have emerged as another important development in hematology diagnostics. These systems capture high-resolution images of stained blood films and use image analysis software for automated or semi-automated preclassification of cells. They improve laboratory workflow by reducing the time required for manual slide review and by supporting standardization in cell identification.

One important advantage of digital imaging is reproducibility. Since images can be stored, reviewed, and shared, digital systems improve documentation and quality assurance. They also support telehematology and remote consultation, which is valuable when expert hematopathologists are not immediately available. In educational settings, digital images provide useful training material for students and laboratory staff.

Digital imaging also has limitations. Automated image recognition may not always classify abnormal or poorly stained cells correctly, and certain complex morphological findings still require expert review. Performance depends on slide quality, staining consistency, and software capability. Like flow cytometry, digital imaging requires investment in equipment, maintenance, and training. Its best use is therefore as a supportive technology that enhances, rather than replaces, professional judgment.

Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Raza et al - 2026

DOI: http://doi.org/10.5281/zenodo.20120048

Integrated Diagnostic Approach

A key finding of this review is that no single hematology diagnostic method is sufficient in all situations. Manual microscopy provides essential morphological detail. Automated analyzers offer speed and efficiency in routine testing. Flow cytometry provides sensitive immunophenotypic and multiparametric analysis. Digital imaging improves standardization, documentation, and workflow. The most reliable diagnostic model integrates these methods according to clinical need. For example, an automated analyzer may first identify abnormalities, a peripheral smear may then clarify the morphology, and flow cytometry may subsequently confirm lineage or clonality in suspected hematological malignancy. Digital imaging may further support documentation, consultation, and quality control. Such integration improves both diagnostic accuracy and laboratory efficiency.

Future Direction

The future of hematology is likely to involve even greater integration of automation, digital platforms, and artificial intelligence. AI-based image analysis and machine learning systems may improve automated cell recognition, flagging accuracy, and workflow optimization. Even so, successful adoption of such innovations will require validation, standardization, quality assurance, and continuous training of laboratory personnel. Human expertise will remain central, especially in complex or ambiguous cases.

LIMITATIONS OF THE REVIEW

This review has some limitations. First, the included studies differed in design, sample size, methodology, and diagnostic focus, which limits direct comparison between findings. Second, because this is a narrative review, study selection may be influenced by availability and relevance, which may introduce selection bias. Third, the strength of the conclusions depends on the quality of the studies reviewed. Any weaknesses in the original studies may affect the reliability of the overall interpretation. In addition, the rapid pace of technological development in hematology means that

Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20120048

some information may become outdated over time. Finally, this review does not include formal cost analysis, despite the fact that cost and access are important issues in the adoption of advanced technologies.

CONCLUSION

This review shows that hematological diagnostics has progressed from a primarily manual and morphology-based discipline to a more advanced, automated, and technology-supported field. Manual methods, especially peripheral blood smear examination, remain essential for detailed morphological assessment and for resolving complex or doubtful findings. Automated hematology analyzers have improved routine laboratory efficiency and standardization. Flow cytometry has transformed immunophenotyping and the diagnosis of hematological malignancies through rapid and highly sensitive cellular analysis. Digital imaging has strengthened workflow, documentation, standardization, and remote consultation.

No single method meets all diagnostic needs in hematology. The most effective approach is a combined one in which manual expertise is supported by modern technologies. Such an integrated strategy offers greater diagnostic accuracy, better laboratory performance, and improved patient care. As hematology continues to evolve, the successful combination of conventional skills with technological innovation will remain central to high-quality diagnostic practice.

RECOMMENDATIONS

Future research should focus on developing affordable and accessible hematology technologies for use in both advanced and resource-limited laboratories. Greater effort is needed to integrate manual methods with flow cytometry, digital imaging, and automation in a way that improves reliability without reducing clinical relevance. Artificial intelligence and machine learning should be further explored for automated cell analysis, image interpretation, and workflow improvement. Standardized operating procedures and quality control guidelines should be strengthened to

Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379
Raza et al - 2026
DOI: http://doi.org/10.5281/zenodo.20120048

improve consistency among laboratories. Continuous education and technical training for laboratory personnel are also essential for the effective and safe use of emerging technologies. Further large-scale studies are needed to evaluate clinical effectiveness, cost-benefit, and practical implementation in routine hematology diagnostics.

CONFLICT OF INTEREST

The author declares no conflict of interest.

REFERENCES

Hoffman, R., Benz, E. J., Jr., Silberstein, L. E., Heslop, H. E., Weitz, J. I., & Salama, M. E. (Eds.). (2022). *Hematology: Basic principles and practice* (8th ed.). Elsevier.

Bain, B. J., Bates, I., Laffan, M. A., & Lewis, S. M. (2016). *Dacie and Lewis practical haematology* (12th ed.). Elsevier.

Bain, B. J., & Leach, M. (in press). *Blood cells: A practical guide* (6th ed.). Wiley Blackwell. (Expected 2025)

McKenzie, S. B., & Williams, J. L. (2015). *Clinical laboratory hematology* (3rd ed.). Pearson.

Brown, M., & Wittwer, C. (2000). Flow cytometry: Principles and clinical applications in hematology. *Clinical Chemistry, 46*(8 Pt 2), 1221–1229.

Shapiro, H. M. (2003). *Practical flow cytometry* (4th ed.). Wiley-Liss.

Kratz, A., Lee, S. H., Zini, G., Riedl, J. A., Hur, M., Machin, S. J., & International Council for Standardization in Haematology. (2019). Digital morphology analyzers in hematology: ICSH review and recommendations. *International Journal of Laboratory Hematology, 41*(4), 437–447. https://doi.org/10.1111/ijlh.13042

Lewis, J. E., & Pozdnyakova, O. (2023). Digital assessment of peripheral blood and bone marrow aspirate smears. *International Journal of Laboratory Hematology, 45*(Suppl. 2), 50–58. https://doi.org/10.1111/ijlh.14082

Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387
Print ISSN 3007-2379

Raza et al - 2026
DOI: http://doi.org/10.5281/zenodo.20120048

Chase, M. L., Drews, R. E., Zumberg, M. S., Ellis, L. R., Reid, E. G., Gerds, A. T., & Blood and Marrow Transplant Clinical Trials Network. (2023). Consensus recommendations on peripheral blood smear review: Defining curricular standards and fellow competency. *Blood Advances, 7*(13), 3244–3252. https://doi.org/10.1182/bloodadvances.2023009843

Gulati, G., Uppal, G., & Gong, J. (2022). Unreliable automated complete blood count results: Causes, recognition, and resolution. *Annals of Laboratory Medicine, 42*(5), 515–530. https://doi.org/10.3343/alm.2022.42.5.515

Comar, S. R., Malvezzi, M., & Pasquini, R. (2017). Evaluation of criteria of manual blood smear review following automated complete blood counts in a large university hospital. *Revista Brasileira de Hematologia e Hemoterapia, 39*(4), 306–317.

Katz, B. Z., Benisty, D., Sayegh, Y., Lamm, I., & Avivi, I. (2022). Remote digital microscopy improves hematology laboratory workflow by reducing peripheral blood smear analysis turnaround time. *Applied Clinical Informatics, 13*(5), 1108–1115. https://doi.org/10.1055/a-1957-6219

Zini, G. (2024). Hematological cytomorphology: Where we are. *International Journal of Laboratory Hematology, 46*(5), 789–794.

Adewoyin, A. S., & Nwogoh, B. (2014). Peripheral blood film, a review. *Annals of Ibadan Postgraduate Medicine, 12*(2), 71–79.

Dadelahi, A., Szczepiorkowski, Z. M., & Dunbar, N. M. (in press). Applications of flow cytometry in diagnosis and monitoring of hematologic disorders. *Clinics in Laboratory Medicine, 44*(2). (DOI to be assigned)

Furundarena, J. R., Araiz, M., Urrechaga, E., Aguirre, U., Aguinaga, A., Sainz, M. R., & Basabe, P. (2017). Comparison of abnormal cell flagging of the hematology analyzers Sysmex XN and Beckman Coulter DxH 800 in the detection of peripheral blood leukocyte abnormalities. *International Journal of Laboratory Hematology, 39*(5), 483–490.

Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387
Print ISSN 3007-2379

Raza et al - 2026
DOI: http://doi.org/10.5281/zenodo.20120048

Ramiah, J., Gannamani, V., Jugathambal, K., & et al. (2023). Performance of the automated Sysmex XN-3000 analyser for detection of white blood cell abnormalities compared with peripheral blood smear microscopy. *Journal of Clinical Pathology, 76*(8), 542–547.

Kumar, A., Matreja, P. S., Singh, V. K., & Awasthi, S. (in press). Comparison of cytochemistry and flow cytometry for leukemia immunophenotyping: A systematic review and meta-analysis. *Russian Journal of Immunology*. https://doi.org/10.46235/1028-7221-17305-COC (Expected 2025)

Kim, H., et al. (2025). Performance of the automated digital cell image analyzer UIMD PBIA in white blood cell classification: A comparative study with Sysmex DI-60. *Clinical Chemistry and Laboratory Medicine, 63*(7), 1409–1418. https://doi.org/10.1515/cclm-2024-1323

Sacchetti, S., et al. (2025). Comparative analysis of the performance of automated digital cell morphology analyzers for leukocyte differentiation in hematologic malignancies: Mindray MC-80 versus West Medical Vision Hema Pro. *International Journal of Laboratory Hematology, 47*(4), 643–650. https://doi.org/10.1111/ijlh.14470

Coussee, A., Robbrecht, J., Maelegheer, K., Vandewal, W., & Florin, L. (2025). Evaluating the performance of the new Sysmex XR-Series haematology analyser: A comparative study with the Sysmex XN-Series. *LabMedicine, 2*(1), 5. https://doi.org/10.3390/labmed2010005

De Iuliis, V., Chiatamone Ranieri, S., et al. (2025). Performance evaluation of the Scopio Labs X100HT digital morphology analyzer and abnormal cell detection in peripheral blood smears. *International Journal of Laboratory Hematology, 47*, e70005. https://doi.org/10.1111/ijlh.70005

Bowers, K. A., & Nakashima, M. O. (2024). Digital imaging and AI pre-classification in hematology. *Clinics in Laboratory Medicine, 44*(3), 397–408. https://doi.org/10.1016/j.cll.2024.04.002

Deltadahl, S., et al. (2025). Deep generative classification of blood cell morphology. *Nature Machine Intelligence, 7*, 1791–1803. https://doi.org/10.1038/s42256-025-01122-7

Online ISSN 3007-2387

Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20120048

Nass, S. A., et al. (2020). Hemoglobin point-of-care testing in rural Gambia: Comparing accuracy of HemoCue and Aptus with an automated hematology analyzer. *PLoS ONE, 15*(10), e0239931. https://doi.org/10.1371/journal.pone.0239931

Smart, L. R., et al. (2016). Evaluation of a portable haemoglobin metre performance in children with sickle cell disease and implications for healthcare in resource-poor settings. *American Journal of Hematology, 91*(6), E292–E296. (PubMed)

Mishra, P., et al. (2024). Digital morphology compared to the optical microscope: A validation study on reporting bone marrow aspirates. *International Journal of Laboratory Hematology, 46*(2), 295–302. https://doi.org/10.1111/ijlh.14238

Fu, X., et al. (2020). Morphogo: An automatic bone marrow cell classification system on digital images analyzed by artificial intelligence. *Acta Haematologica, 143*(6), 543–550. https://doi.org/10.1159/000509524

Cai, Q., Lan, H., Yi, D., et al. (2025). Flow cytometry in acute myeloid leukemia and detection of minimal residual disease. *Clinica Chimica Acta, 564*, 119945. https://doi.org/10.1016/j.cca.2024.119945

Paiva, B., et al. (2025). Prognostic value of minimal residual disease detected by EuroFlow next-generation flow cytometry and next-generation sequencing in patients with multiple myeloma. *Haematologica, 110*(9), 2160–2170. https://doi.org/10.3324/haematol.2025.287411

Al Naam, Y. A., et al. (2022). The impact of total automation on the clinical laboratory workforce: A case study. *Journal of Healthcare Leadership, 14*, 55–62. https://doi.org/10.2147/JHL.S362614

Zahran, N., et al. (2019). Improving laboratory processes with total laboratory automation. *Journal of Pathology Informatics, 10*, 20. (PubMed)

Patel, R., et al. (2025). Unstained blood smear analysis: A review of rule-based, machine learning, and deep learning techniques. *Artificial Intelligence in Medicine, 162*, 102987. (PubMed)

Online ISSN 3007-2387

Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20120048

Shakah, H., et al. (2025). Standardizing stem cell enumeration: A methodological comparison of single and dual flow cytometry platforms. *Cytometry Part B: Clinical Cytometry*, e70034. https://doi.org/10.1002/cyto.b.70034

Ehinger, M., & Béné, M. C. (2024). Morphology and multiparameter flow cytometry combined for integrated lymphoma diagnosis on small volume samples: Possibilities and limitations. *Virchows Archiv, 485*(5), 789–798. https://doi.org/10.1007/s00428-024-03819-3

Albarède, S., et al. (2025). EQALM recommendations for the analytical performance specifications for blood smear interpretation in hematology: A need for standardization. *Clinical Chemistry and Laboratory Medicine, 64*(2), 479–488. https://doi.org/10.1515/cclm-2025-1011

ICSH Working Group. (2023). International Council for Standardization in Haematology guidance for new lot verification of coagulation reagents, calibrators, and controls. *Seminars in Thrombosis and Hemostasis, 49*(8), 815–822. https://doi.org/10.1055/s-0043-1771388

Shrestha, S., et al. (2025). A comparative study of platelet counts by automated and manual method in patients with thrombocytopenia and thrombocytosis. *Nepal Medical College Journal, 27*(2), 118–123. https://doi.org/10.3126/nmcj.v27i2.80538

Jain, S., et al. (2021). Comparison between manual and automated methods of counting reticulocytes and the effect of sample storage on reticulocyte count: A cross-sectional study from Southern India. *Journal of Laboratory Physicians, 13*(1), 15–20. https://doi.org/10.1055/s-0041-1727562

Kulshrestha, A., et al. (2014). Manual and automated reticulocyte counts. *Journal of Clinical and Diagnostic Research, 8*(3), FC01–FC04. (PubMed)

Kunwar, A., et al. (2008). Digital image analysis of mean AgNOR area objectively discriminates between reactive plasmacytosis and multiple myeloma in cytologic smears from bone marrow aspirates. *Acta Cytologica, 52*(5), 554–560. https://doi.org/10.1159/000151711

Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20120048

Kalina, T., et al. (2019). EuroFlow standardization of flow cytometry for immunophenotyping. *Journal of Immunological Methods, 475*, 112654. (Reference from DOI search result)

CLSI. (2021). *Validation of assays performed by flow cytometry* (CLSI document H62). Clinical and Laboratory Standards Institute. (PubMed)

Bergeron, M., et al. (2002). Comparison of interlaboratory variation in absolute T-cell counts by single-platform and optimized dual-platform methods. *Cytometry, 50*(6), 290–297. (PubMed)

Ali, S., et al. (2025). Comparative study of blood hemoglobin between calculated method through ABG analyzer and impedance method through fully automated blood cell counter. *Journal of Laboratory Physicians, 17*(2), 145–150. https://doi.org/10.1055/s-0045-1801523

Khan, M. A., et al. (2021). Performance evaluation of nucleated red blood cell (NRBC) count using a fully automated haematology analyzer versus manual counting. *Pakistan Army Medical Journal, 71*(5), 1723–1727. https://doi.org/10.51253/pafmj.v71i5.5706

Beazley, C., et al. (2021). Point-of-care haematology analyser quality assurance programme: A rural nursing perspective. *Australian Journal of Rural Health, 29*(3), 412–418. (PubMed)

Hu, Z., et al. (2023). Multimodal gated mixture of experts using whole slide image and flow cytometry for multiple instance learning classification of lymphoma. *Journal of Pathology Informatics, 14*, 100340. (PubMed)