



Research Article

A Review of Flow Cytometry and Artificial Intelligence in Haematologic Diagnosis

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Abstract

Traditionally, the diagnosis and classification of haematologic illnesses have depended on morphological examination, cytochemistry, and manual cell counting methods. However, improvements in flow cytometry and artificial intelligence (AI) have changed haematologic diagnostics by making it possible to do high-throughput, objective, and very accurate cellular analyses. Flow cytometry enables the multiparametric enumeration of biological markers, whereas AI algorithms improve pattern identification, data interpretation, and diagnostic precision. This study examines the principles, applications, and integration of flow cytometry and artificial intelligence in haematologic diagnosis, highlighting their complementary functions in contemporary laboratory practice.

Keywords: Flow Cytometry, Artificial Intelligence, Haematologic, Diagnosis.

Introduction

The haematologic system, which includes blood cells and their precursors, is very important for keeping the body in balance, moving oxygen around, and fighting off infections. Historically, the diagnosis of haematologic illnesses, including leukaemias, lymphomas, anaemias, and myelodysplastic syndromes, has relied on morphological evaluations utilising microscopy, cytochemical stains, and manual differential counts. While these traditional techniques have yielded critical diagnostic information, they frequently exhibit subjectivity and are constrained by human error and variability across observers. As a result, the need for more objective, quantitative, and high-throughput methods has led to the use of current technologies like flow cytometry and artificial intelligence (AI) in diagnostic haematology [1].

Flow cytometry is a complicated way to measure the physical and chemical properties of cells or particles as they flow through a laser beam one at a time. As each cell passes through the beam, it scatters light and gives off fluorescence signals based on the fluorochrome-labeled antibodies that are bound to certain cellular markers. The signals that come out are processed electronically to make multiparametric data that describes several aspects of the cells, such as their size, granularity, and antigen expression. A flow cytometer usually has three main parts: the fluidics system, which moves and aligns cells in a single stream; the optics system, which uses lasers and detectors to measure forward scatter, side scatter, and fluorescence; and the electronics and software system, which turns signals into data that can be understood and displayed in graphs or dot plots [2].

Flow Cytometry's Uses in Haematologic Diagnosis

Flow cytometry is powerful because it can quickly look at hundreds of cells per second and provide you rich immunophenotypic information that is important for identifying and classifying blood diseases. It is especially useful for finding unusual patterns of antigen expression in lymphomas and leukaemias. The co-expression of CD5 and CD19 is indicative of chronic lymphocytic leukaemia (CLL), whereas the presence of CD34 and CD117 signifies acute myeloid leukaemia (AML). Flow cytometry helps figure out lineage, classify diseases, and see how well treatments are working by giving objective immunophenotypic profiles [3]. One of the most important uses of flow cytometry in haematology is finding minimal residual disease (MRD). MRD is the small amount of cancerous cells that stay in the body after treatment and could cause a relapse. Flow cytometry is very sensitive and can find one cancerous cell amid ten thousand normal cells. This lets doctors see how well a treatment is working and change the treatment plan if necessary. Flow cytometry is also very important for haematopoietic stem cell transplantation. It counts CD34-positive stem cells to find the best moment to collect them and make sure they will successfully engraft. Flow cytometry is also very useful for finding immunodeficiencies and cytopenias since it can count several types of immune cells, like T cells, B cells, and natural killer cells [4].

AI in Haematologic Diagnosis

Alongside the advancement of flow cytometry, artificial intelligence has arisen as a revolutionary instrument in medical diagnosis. AI is short for "artificial intelligence," which is a type of computer system that learns from data, finds patterns, and makes predictions or choices. AI applications in haematologic diagnostics include data mining, picture recognition, predictive modelling, and automated interpretation. Machine learning (ML), a part of AI, uses algorithms that get better as they learn from experience and get more data. To group cell populations and predict illness outcomes, people use common machine learning methods like random forests, support vector machines, and k-nearest neighbours [5]. Deep learning (DL) is a more advanced type of AI that uses artificial neural networks, especially convolutional neural networks (CNNs), to automatically find hierarchical features in huge, complicated datasets. These networks can look at digital pictures of blood smears or flow cytometric profiles and find aberrant cells like blasts or dysplastic forms with amazing accuracy. Digital hematopathology has also started using AI algorithms to automate the inspection of peripheral blood and bone marrow smears. This makes the job easier for lab workers and reduces the chance of human error. AI-driven prediction and prognostic models also use multi-omics and clinical data to guess how well a medication will work and how long a patient will live. Neural networks trained on integrated genetic and immunophenotypic data have demonstrated considerable efficacy in predicting recurrence risks in leukaemia patients, hence facilitating personalised therapy [6].

Combining Flow Cytometry with AI

Combining flow cytometry with artificial intelligence is a big step forward in diagnostic haematology. Flow cytometry produces extensive high-dimensional data necessitating advanced analytical methods for comprehensive interpretation. AI algorithms are great at working with these kinds of complicated datasets, which makes the two technologies work very well together. One big area of integration is in automatic gating and figuring out what the data means. Flow cytometric gating is a manual technique that is typically subjective and can be different for each operator. AI-driven algorithms now automate this procedure, making it possible to find aberrant populations and group cells based on antigen expression without bias. Flow SOM, t-SNE (t-distributed stochastic neighbour embedding), and UMAP (Uniform Manifold Approximation and Projection) are examples of unsupervised learning methods that can help make multidimensional flow cytometry data easier to understand and more accurate for diagnosis [7]. Using AI and flow cytometry together has been demonstrated to make diagnoses more accurate, make them more reproducible, and cut down on the time it takes to evaluate results. AI-assisted flow cytometry systems may automatically find samples that are not normal, suggest possible diagnostic categories, and flag results for expert assessment. This speeds up the work flow and cuts down on turnaround times in busy haematology labs. These systems help standardise laboratories and make them more efficient by providing decision-support tools and automated quality control [8]. Even though AI and flow cytometry integration have a lot of potential, there are still a lot of problems to solve. One big problem is that data standardisation across labs is hard since different cytometer setups, reagents, and analytical techniques can make it hard to compare results. Furthermore, the "black-box" quality of many AI algorithms makes it hard to understand and trust them, which are both important for clinical acceptability. Ethical and regulatory issues, especially those related to patient data protection and algorithm validation, are also big problems. Using these technologies correctly necessitates interdisciplinary collaboration among doctors, laboratory scientists, and data engineers, together with suitable training to guarantee precise interpretation and supervision [9]. The merging of AI and flow cytometry is likely to move haematologic diagnosis closer to precision medicine. Future innovations will likely involve combining cytometric data with genetic and proteomic data to make more complete diagnostic models. Cloud-based databases and federated learning platforms will make it easier for people all over the world to share data, which will help diagnostic algorithms get better all the time. Also, the creation of "smart cytometers" with built-in AI analytics will make it possible to analyse data in real time at the point of treatment, making advanced diagnostics available even in places with few resources.

Conclusion

Artificial intelligence and flow cytometry have completely changed the way haematologic diagnosis is done. Flow cytometry is a strong tool for analysing cells in high resolution, and AI makes it easier to understand data, find patterns, and make predictions. These technologies are changing haematology from a field based on morphology to one based on data that is objective, precise, and automated. There are still problems with standardisation, validation, and ethical governance, but the combination of AI and flow cytometry marks the beginning of a new era of diagnostic excellence in haematology. To fully realise the promise of these advances in enhancing patient care and outcomes, we will need to keep doing research, improve technology, and work with people from many fields.

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