AUCTORES
Globalize your Research

Journal of Clinical Research and Reports

Gerhard Zugmaier*

Open Access

Research Article

Boolean Algebra (Mathematical Logic) for Diagnosis of Hematologic Disorders

Gerhard Zugmaier

Department of Haematology, Oncology and Immunology, Philipps University Marburg, Marburg, Germany.

***Corresponding Author:** Gerhard Zugmaier, Department of Haematology, Oncology and Immunology, Philipps University Marburg, Marburg, Germany.

Received date: May 20, 2025; **Accepted date:** June 16, 2025; **Published date:** June 24, 2025

Citation: Gerhard Zugmaier, (2025), Boolean Algebra (Mathematical Logic) for Diagnosis of Hematologic Disorders, *J Clinical Research and Reports*, 20(1); **DOI:**10.31579/2690-1919/539

Abstract

Background: Using Boolean algebra to assist in the diagnosis of hematologic disorders involves applying logical operations (AND, OR, NOT, etc.) to symptoms, lab values, and clinical findings to arrive at probable diagnoses.

Aim: This study used Boolean algebra (mathematical logic) to calculate the diagnosis of hematologic disorders.

Results: Each lab value and clinical finding was encoded as a Boolean variable. The solution of the Boolean equations was risking the of hematologic disorders.

Conclusion: Boolean algebra can be used to precisely calculate the diagnosis of hematologic disorders.

Keywords: boolean algebra; linear equations computational medicine; hematologic disorders; diagnosis

Introduction

Mathematics plays a vital and growing role in modern medicine, serving as the foundation for diagnostics, treatment planning, research, and healthcare systems. From modeling disease progression to interpreting medical images and optimizing healthcare delivery, mathematical techniques offer precision and predictive power. There are several key areas where Mathematics is used in Medicine. Medical Imaging. Mathematical algorithms are essential in CT, MRI, PET, and ultrasound reconstruction. Fourier transforms are applied in MRI and signal processing. Image segmentation and enhancement use linear algebra and differential equations. In epidemiology and public health mathematics helps model disease spread using SIR models (Susceptible-Infectious-Recovered), differential equations, reproductive number (R_0) calculations. An example for statistical modeling for outbreak forecasting are the COVID-19 transmission dynamics, which were modeled using systems of nonlinear differential equations. Pharmacokinetics and Pharmacodynamics (PK/PD) describe, how drugs move through the body using compartmental models. Bayesian inference is applied for updating diagnostic probabilities based on new information. Mathematical modeling in physiology has wide applications. It is used for modeling cardiovascular, respiratory, and neural systems, for simulating heart rhythms, lung function, and neuron firing patterns for example by the Hodgkin-Huxley model of nerve impulse transmission. In genomics and bioinformatics statistical genetics, machine learning, and information theory are used to analyze DNA sequences. Sequence alignment, gene expression clustering, and genome-wide association studies (GWAS). An example are hidden Markov models in gene prediction [1 -7].

Boolean algebra offers a structured logical framework for encoding diagnostic rules in medicine. In the context of hematologic disorders, Boolean algebra allows for the systematic use of clinical signs, symptoms, and laboratory results to guide diagnosis through logical operators like AND, OR, and NOT 8.

Using only the OR operator (+) in Boolean algebra for medical diagnostics, especially for hematologic disorders, has benefits in early detection, screening, and rule-out models. Here's a detailed look at the advantages. The OR operator flags any case where at least one abnormal sign or symptom is present. This is ideal for early detection, where missing a diagnosis is riskier than a false positive 9. It ensures no potential cases are missed, a major concern in conditions like leukemia or acute anemia. The OR operator is safer in settings where underdiagnosis can lead to significant harm 10. OR - based algebra is easy to understand, teach, and implement 11. It can be used to create broad alerts when any combination of findings might relate to a family of disorders (e.g., anemia, leukemia, coagulopathies) and it helps flag non-specific findings for follow-up 12.

In this study we use the OR – based algebra to develop a mathematical method of computational diagnosis in hematologic disorders.

Materials and Methods

The mathematical methods have been described in detail elsewhere [8].

Symbols of Boolean Algebra (mathematical logic) [8]

1.Variables:

Each Boolean variable can take one of the values 1 or 0.

2.Operations:

Inclusive OR:

- A + B or A ∨ B
- The result is 1, if A or B or both are 1; if both are 0, the result is 0.
- Example: 1 + 0 = 1 0 + 0 = 0

Equal

- A = B
- The result is 1, if A and B are both 1 or both 0.
- Example: 1 = 1, 0 = 0

Examples of multiple Representations for the same operation7:

- OR (Inclusive OR):
- A + B: Traditional Boolean algebra
- A v B Used in mathematical logic and theoretical fields
- A OR B: Common in programming and textual representations

Increased value ↑

Decreased value ↓

Unchanged value <->

We only use operator v and operator =. Finding x1 v finding x2 v finding x3 = disease (d) does not mean that the disease is defined by these findings but that there is risk, if they are present. This ensures high sensitivity in the diagnostic process.

In the case of multiple variables, it is preferable to use the matrix system 13. The matrix is useful in case findings are missing. In this study we define matrix A by findings available or not. Not available can mean, the parameters are not available, because the investigation or the tests have not been conducted, or they are missing. 1 means the data are available, 0 means they are not available. Matrix X represents the findings. Matrix D shows the disorder. In matrix D value 1 means the disorder can be calculated. Value 0 means the disorder cannot be calculated. In the equations value 1 means the parameter is present, the 0 means the parameter is absent [8]

A				X(findings)		D (disorder) can be calculated
1	1	1	X	x_1	=	1
1	0	1		x_2		1
1	0	0		x_3		1

The matrix is used as follows:

The 1st value in the row is multiplied with the 1st value in the column.

The 2nd value in the row is multiplied with the 2nd value in the column.

The 3rd value in the row is multiplied with the 3rd value in the column.

From the matrix the following equations follow:

x1 v x2 v x3 = D

x1 v x3 = D

x1 = D

In the result section we will provide one example of the matrix presentation.

Results

The findings defining the criteria of risk for the disorders were obtained from the latest current medical diagnosis and treatment 21.
Anemia of chronic disease = normocytic anemia v microcytic anemia v ferritin ↑ v ferritin <-> v transferrin <-> v transferrin ↓

Aplastic anemia = pancytopenia v hypocellular bone marrow
Autoimmune hemolytic anemia = IgG autoantibody v spherocytes v reticulocytes ↑ v positive Coombs test

Cold agglutinin disease = reticulocytes ↑ v positive Coombs test v cold agglutin titer

Folic acid deficiency = macrocytic anemia v hyper segmented neutrophils v folic acid ↓

Glucose – 6 phosphate deficiency = X – linked v hemolytic anemia v bite cells v blister cells v glucose – 6 - phosphate ↓

Iron deficiency = ferritin ↓ v bleeding v response to iron therapy

Neutropenia = neutrophils < 1800/µl = 1.8 x 109 /L

Neutropenia severe = neutrophils < 500/µl = 0.5 x 109 /L

Paroxysmal nocturnal hemoglobinuria = episodic hemoglobinuria v thrombosis v hemolytic anemia v pancytopenia v CD55 ↓ v CD59 ↓

Sickle cell anemia = positive family history v sickled cells v hemolytic anemia

Thalassemia = microcytic anemia v positive family history v red blood cell count ↑ v abnormal red blood cell morphology

Vitamin B12 deficiency = macrocytic anemia v hyper segmented neutrophils v vitamin B12 ↓

A				X		D
1	1	1		ferritin ↓		1
1	0	1		bleeding		1
1	0	0		response to iron therapy		1
1	1	0	X		=	1
0	1	1				1
0	0	1				1
0	0	0				0
0	1	0				1

Iron deficiency as an example of matrix presentation

A = 1 (finding available), A = 0 (finding unavailable) D = 1 (disorder can be calculated), D = 0 (disorder cannot be calculated)

The matrix is used as follows (see methods):

The 1st value in the row is multiplied with the 1st value in the column.

The 2nd value in the row is multiplied with the 2nd value in the column.

The 3rd value in the row is multiplied with the 3rd value in the column.

1 x ferritin ↓= 1, 1 x bleeding = 1, 1 x response to iron therapy = 1

Then iron deficiency can be calculated as:

Iron deficiency = ferritin ↓ v bleeding v response to iron therapy

1 x ferritin ↓= 1, 1 x bleeding = 0, 1 x response to iron therapy = 1

Then iron deficiency can be calculated as:

Iron deficiency = ferritin ↓ v response to iron therapy

1 x ferritin ↓= 1, 0 x bleeding = 0, 0 x response to iron therapy = 0

Then iron deficiency can be calculated as:

Iron deficiency = ferritin ↓

1 x ferritin ↓= 1, 1 x bleeding = 1, 0 x response to iron therapy = 0

Then iron deficiency can be calculated as:

Iron deficiency = ferritin ↓ v bleeding

0 x ferritin ↓= 0, 1 x bleeding = 1, 1 x response to iron therapy = 1

Then iron deficiency can be calculated as:

Iron deficiency = bleeding v response to iron therapy

0 x ferritin ↓= 0, 0 x bleeding = 0, 1 x response to iron therapy = 1

Then iron deficiency can be calculated as:

Iron deficiency = response to iron therapy

0 x ferritin ↓= 0, 0 x bleeding = 0, 0 x response to iron therapy = 0

Then iron deficiency cannot be calculated as:

Iron deficiency = not assessable

0 x ferritin ↓= 0, 1 x bleeding = 1, 0 x response to iron therapy = 0

Then iron deficiency can be calculated as:

Iron deficiency = bleeding

Discussion:

In this study we have applied OR – based Boolean matrices for diagnosis of hematologic disorders. These disorders present an ideal model for such an approach due to their clear diagnostic criteria. The OR – based algebra ensures high sensitivity and simplicity. This algebraic approach needs to be discriminated against a linguistic formal logic approach. Finding x1 v finding x2 v finding x3 = disease (d) does only mean, the risk of disease is present but not the disease per se. This distinction is crucial for accurately interpreting the results and understanding the implications of our findings

Mathematics not only plays a role in medicine in general but also especially a crucial role in medical diagnostics by providing tools for modeling biological systems, analyzing medical data, and improving the accuracy and efficiency of diagnostic procedures.

Algorithms based on linear algebra, calculus, and optimization are used to detect patterns in medical data for disease prediction. Deep learning models are widely applied in radiology, pathology, and dermatology [14]

Techniques like Fourier transforms, wavelet analysis, and image reconstruction algorithms (e.g., filtered back projection in CT scans) rely heavily on mathematical models. Mathematics helps enhance image resolution, reduce noise, and improve diagnosis from MRI, CT, PET, and ultrasound 15.

High-dimensional data from gene expressions, DNA sequencing, and proteomics are analyzed using multivariate statistics, clustering, and principal component analysis (PCA) [16]

Thus, mathematics is integral to the evolution of medical diagnostics. From theoretical foundations to practical implementation in technologies and algorithms, it facilitates accurate, personalized, and data-driven diagnosis. As medical data becomes increasingly complex, the role of mathematics will only grow in significance.

Boolean algebra is a powerful tool in medicine, providing a framework for decision-making, device control, and biological modeling. Its simplicity and precision make it ideal for applications where binary outcomes and rule-based reasoning are critical [17 -19]

A Boolean matrix is a matrix consisting only of binary values (0 and 1), representing the absence or presence of features (e.g., symptoms, test results). When using only the OR operator, diagnostic models identify conditions that require at least one of several possible criteria to be met to suggest a particular disease.

Advantages of OR-Based Boolean Matrices in Diagnosis are simplicity, sensitivity, speed. They are easy to implement in clinical decision support tools. They ensure that cases are not missed due to overly restrictive criteria. They permit rapid processing for high-volume screening (e.g., in pandemics) [23].

Limitations are low specificity and lack of grading. OR-Based Boolean matrices tend to produce false positives since any one symptom triggers a positive result. They cannot prioritize or weigh symptoms by importance without extending beyond Boolean algebra [20]

Conclusion

OR – based Boolean matrices offer a straightforward method for encoding and processing diagnostic rules, especially when high sensitivity is prioritized over specificity. They are particularly useful in initial screenings, syndromic surveillance, and rule-based triage systems.

References

1. Edelstein-Keshet L. (2005). Mathematical Models in Biology. SIAM,
2. Murray JD. (2002). Mathematical Biology. Springer
3. Otto SP, Day T. (2007). A Biologist's Guide to Mathematical Modeling in Ecology and Evolution. Princeton,
4. Kaplan D. (1995). Understanding Nonlinear Dynamics. Springer,
5. Weisstein EW. CRC Concise Encyclopedia of Mathematics. CRC Press, 2002.
6. Kirkwood BR, Sterne JAC. Essential Medical Statistics. Wiley-Blackwell, 2003.
7. Gonzalez RC, Woods RE. (2017). Digital Image Processing. Pearson, (for medical imaging math).
8. Gerhard Zugmaier, (2025), Boolean Algebra (Mathematical Logic) for computational Differential Diagnosis in Medicine, J Clinical Research and Reports, 18(1)
9. Aakre CA et al., (2017), Development of a clinical decision support tool for anemia workup. BMC Med Inform Decis Mak,
10. Ramesh AN et al., (2004). Artificial Intelligence in Medicine. Ann R Coll Surg Engl,
11. Berner ES (ed). (2016). Clinical Decision Support Systems: Theory and Practice. Springer,
12. Shortliffe EH.(1976). Computer-Based Medical Consultations: MYCIN. Elsevier,
13. Whitesitt JE, (2010).Boolean Algebra and Its Applications, Dover
14. Esteva, A., et al. (2017). "Dermatologist-level classification of skin cancer with deep neural networks." Nature, 542(7639), 115–118.
15. Kak, A. C., & Slaney, M. (2001). Principles of Computerized Tomographic Imaging. Society for Industrial and Applied Mathematics (SIAM).
16. Hastie, T., Tibshirani, R., & Friedman, J. (2009). The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Springer.
17. Kutz, M. (2016). Biomedical Engineering and Design Handbook: Volume 1: Biomedical Engineering Fundamentals (2nd ed.). McGraw-Hill Education.
18. Shmulevich, I., Dougherty, E. R., & Zhang, W. (2002). Gene perturbation and intervention in probabilistic Boolean networks. Bioinformatics, 18(10), 1319–1331.
19. Shortliffe, E. H., & Cimino, J. J. (2013). Biomedical Informatics: Computer Applications in Health Care and Biomedicine (4th ed.). Springer.
20. Richesson, R. L., & Andrews, J. E. (2019). Clinical Research Informatics. Springer. (Chapter on decision logic in clinical trials).
21. Papadakis MA, Rabow MW, McQuaid KR, Gandhi M. eds. Current Medical Diagnosis & Treatment 2025. McGraw-Hill Education; 2025. Accessed May 22, 2025.
22. Badawi, A. (2016). Matrix Algebra, Basics of. In: Alhajj, R., Rokne, J. (eds) Encyclopedia of Social Network Analysis and Mining. Springer, New York, NY.
23. Serge Bouc, Jacques Thévenaz, The algebra of Boolean matrices, correspondence functors, and simplicity. J. Comb. Algebra 4 (2020), no. 3, pp. 215–267

DOI:10.31579/2690-1919/539