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Formal Logic and Flowchart for Diagnosis Validity Verification and Inclusion in Clinical Decision Support Systems

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Abstract. Logical reasoning is part of medical practice since its origins. Modern Medicine has included information-intensive tools to refine diagnostics and treatment protocols. We are introducing formal logic teaching in Medical School prior to Clinical Internship, to foster medical practice. Two simple examples (Acute Myocardial Infarction and Diabetes Mellitus) are given in terms of formal logic expression and truth tables. Flowcharts of both diagnostic processes help understand the procedures and to validate them logically. The particularity of medical information is that it is often accompanied by “missing data” which suggests to adapt formal logic to a “three state” logic in the future. Medical Education must include formal logic to understand complex protocols and best practices, prone to mutual interactions.

1. Introduction

Medical education in the twenty-first century faces the challenge of maintaining a high level of quality without losing the empathy of the doctor-patient relationship. The amount of acquired and research generated knowledge increases exponentially, making it difficult to update people and institutions.

Concomitantly, information technologies provide a possibility to go beyond the difficulties of information management. Medical reasoning has always included logical thinking. In particular, the intellectual processes resulting in diagnostic and therapeutic decisions may be seen as following a tree-type structure in its many forms.

The wide span of procedures to choose from, all with many pieces of information to consider calls for the inclusion of formal logic in the study and practice of medicine. We suggest here how two examples related to common diagnostics may be prepared for inclusion into clinical decision support systems (CDSS). This formal modality is also better adapted for electronic health records (EHR) and other documentation support media.



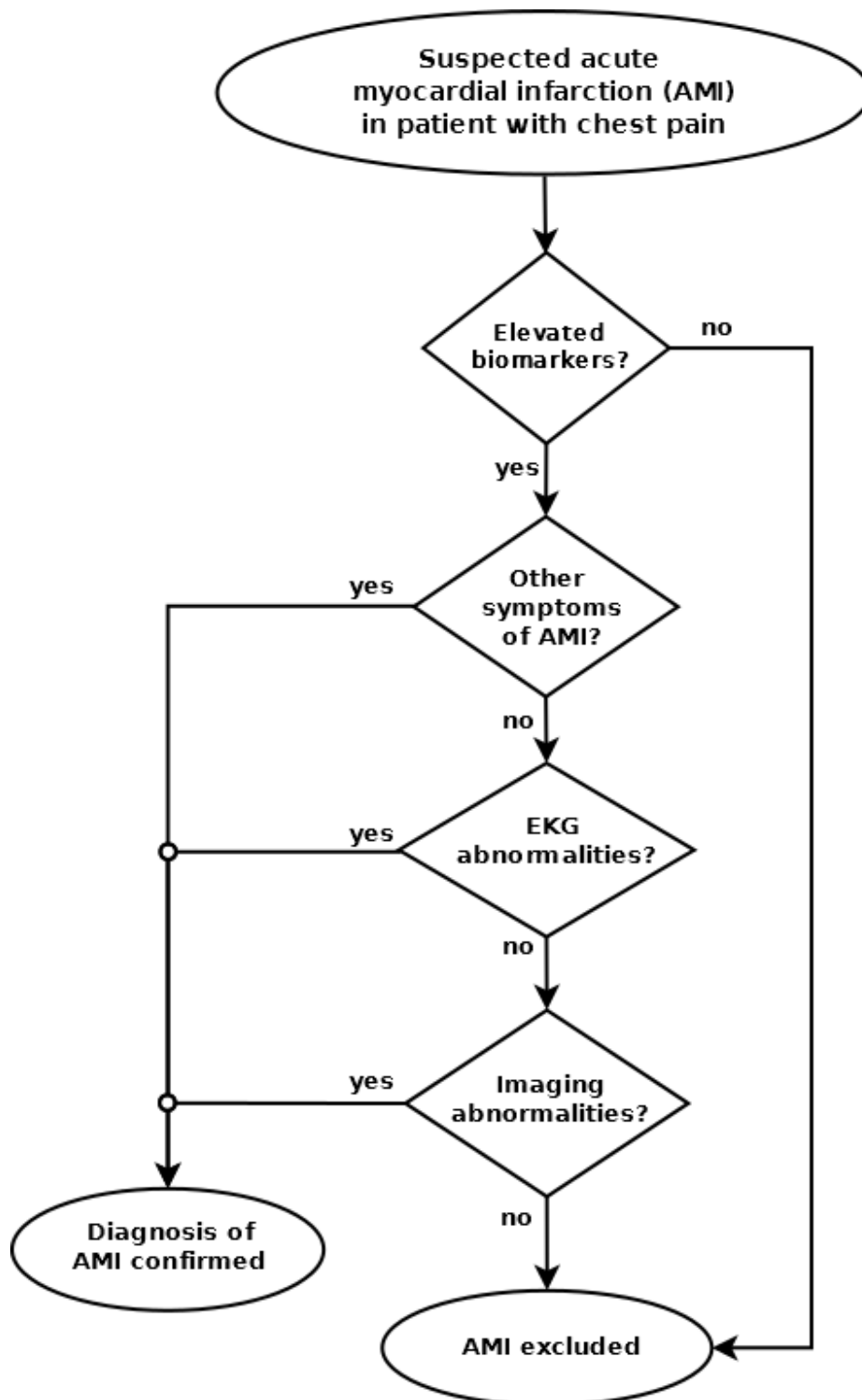


Figure 1. Flowchart for Acute Myocardial Infarction diagnosis. (OGTT: Oral glucose tolerance test).

2. Objectives

The objective of this study is to provide elements for discussion on the usefulness of teaching formal logic in medical training. Medical students can improve and systematize their medical reasoning, specifically during diagnostic and therapeutic decision-making.

As a corollary, this approach assimilates complex diagnostic and therapeutic processes to logical formulae, truth tables and flowcharts that can be easily incorporated into clinical decision support systems.

3. General method

The method we have adopted consists of the following steps:

- I. identification of the premises contained in a statement or protocol;
- II. study of the link between each premise and identification of logical connective operators (AND, OR, IF, etc.);
- III. formal logical expression;
- IV. construction of the truth table, and
- V. analysis of the results.

In addition, flowcharts follow standard ISO 5807: 1985 nomenclature [1], to allow better and quicker understanding of complex clinical guidelines, using Information Technology applications.

4. Implementation examples

Consider two simple and frequent examples of diagnostic processes: acute myocardial infarction (AMI) and diabetes mellitus (DM).

4.1. Acute myocardial infarction

According to AMI management guidelines of the European Society of Cardiology (ESC) published in 2013 [2], a diagnosis is based on elevated levels of at least one cardiac biomarker above percentile 99 (especially troponin), plus at least one of the following criteria: symptoms of cardiac ischemia, electrocardiographic (EKG) abnormalities (ST segment elevation or pathological Q waves) and imaging abnormalities (echocardiogram or angiography).

Standard medical practice incorporates these recommendations in the doctor's mental process intuitively appealing to its logical training and experience, that overlaps the pure logical reasoning. The following procedure is a formalization of the diagnostic activity.

4.1.1. Definition of variables

The premises contained in the statement are identified and assigned letters to each:

- p : increase of cardiac biomarkers (troponin)
- q : symptoms of myocardial ischemia
- r : electrocardiographic abnormalities
- s : alterations observed in echocardiogram or angiography
- t : acute myocardial infarction diagnosis

4.1.2. Logical formulation

The formula resulting from the relationship between the identified variables in the statement is:

$$[p \wedge (q \vee r \vee s)] \rightarrow t \quad (1)$$

where \wedge represents the logical AND, \vee the logical OR and \rightarrow implication or conditional.

Table 1. Truth table for Acute Myocardial Infarction diagnosis

p	q	r	s	t	qVr	(qVrVs)	(p^(qVrVs))	(p^(qVrVs))=>t
1	1	1	1	1	1	1	1	1
1	1	1	1	0	1	1	1	0
1	1	1	0	1	1	1	1	1
1	1	1	0	0	1	1	1	0
1	1	0	1	1	1	1	1	1
1	1	0	1	0	1	1	1	0
1	1	0	0	1	1	1	1	1
1	1	0	0	0	1	1	1	0
1	0	1	1	1	1	1	1	1
1	0	1	1	0	1	1	1	0
1	0	1	0	1	1	1	1	1
1	0	1	0	0	1	1	1	0
1	0	0	1	1	0	1	1	1
1	0	0	1	0	0	1	1	0
1	0	0	0	1	0	0	0	1
1	0	0	0	0	0	0	0	1
0	1	1	1	1	1	1	0	1
0	1	1	1	0	1	1	0	1
0	1	1	0	1	1	1	0	1
0	1	1	0	0	1	1	0	1
0	1	0	1	1	1	1	0	1
0	1	0	1	0	1	1	0	1
0	1	0	0	1	1	1	0	1
0	1	0	0	0	1	1	0	1
0	0	1	1	1	1	1	0	1
0	0	1	1	0	1	1	0	1
0	0	1	0	1	1	1	0	1
0	0	1	0	0	1	1	0	1
0	0	0	1	1	0	1	0	1
0	0	0	1	0	0	1	0	1
0	0	0	0	1	0	0	0	1
0	0	0	0	0	0	0	0	1

Note 1: Column “t” refers to the diagnosis of acute myocardial infarction (AMI) and the last column represents the validity of the logical proposition (diagnosis) based on different combinations of values of the variables involved.

Note 2: Diagnosis is based on the result of cardiac biomarkers, presence of cardiac ischemia symptoms, EKG alterations and imaging abnormalities.

4.1.3. Truth table

The truth table resulting from the formula (1) is represented in Table 1 including all possible combinations of values of the variables. The last column indicates whether diagnosis “t” made in each case was correct (1) or incorrect (0).

4.1.4. Particular case management and logic verification

Consider the following particular case: "You are the Physician on call at the emergency room, and you see a patient complaining of a strong precordial pain. When performing an EKG you discover an elevated ST segment in some of the derivations. When the laboratory results arrive you confirm that troponin levels are very high. You therefore diagnose acute myocardial infarction". In this case, the logical formula is:

$$\{[p \wedge (q \vee r \vee s)] \rightarrow t\} \wedge (q \wedge r \wedge p) \rightarrow t \tag{2}$$

resulting in the truth table shown in Table 2. The result indicated in the last column is a tautology, therefore, we conclude that the reasoning is valid.

4.1.5. Flowchart

Figure 1 represents the flowchart of the diagnostic criteria for AMI example.

Table 2. Truth table for Acute Myocardial Infarction diagnosis in a particular case.

p	q	r	s	t	q/r	(q/r/p)	q/r	(q/r/s)	(p/(q/r/s))	((p/(q/r/s))=>t)	((p/(q/r/s))=>t)/(q/r/p)	((p/(q/r/s))=>t)/(q/r/p)=>t
1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	0	1	1	1	1	1	0	0	1
1	1	1	0	1	1	1	1	1	1	1	1	1
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1	1	0	1	0	0	0	1	1	1	0	0	1
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1	0	0	1	0	0	0	0	1	1	0	0	1
1	0	0	0	1	0	0	0	0	0	1	0	1
1	0	0	0	0	0	0	0	0	0	1	0	1
0	1	1	1	1	1	0	1	1	0	1	0	1
0	1	1	1	0	1	0	1	1	0	1	0	1
0	1	1	0	1	1	0	1	1	0	1	0	1
0	1	1	0	0	1	0	1	1	0	1	0	1
0	1	0	1	1	0	0	1	1	0	1	0	1
0	1	0	1	0	0	0	1	1	0	1	0	1
0	1	0	0	1	0	0	1	1	0	1	0	1
0	1	0	0	0	0	0	1	1	0	1	0	1
0	0	1	1	1	0	0	1	1	0	1	0	1
0	0	1	1	0	0	0	1	1	0	1	0	1
0	0	1	0	1	0	0	1	1	0	1	0	1
0	0	1	0	0	0	0	0	1	0	1	0	1
0	0	0	1	1	0	0	0	1	0	1	0	1
0	0	0	1	0	0	0	0	1	0	1	0	1
0	0	0	0	1	0	0	0	0	0	1	0	1
0	0	0	0	0	0	0	0	0	0	1	0	1

4.2. *Diabetes Mellitus*

The Latin American Association Diabetes (ALAD) guidelines published in 2013 [3] comprise diagnostic criteria for diabetes mellitus (DM). In a patient with no suggestive symptoms, the disease is diagnosed with a fasting blood glucose level (in venous blood, after 8 hours of fasting) with a value greater than or equal to 126 mg / dL in two consecutive (both positive) test; with a value in oral glucose tolerance test (venous blood) greater than or equal to 200 mg / dL, repeated in two consecutive tests; or a value of glycosylated hemoglobin (HbA1c) greater than or equal to 6.5%. In a patient presenting symptoms suggestive of diabetes, diagnosis can be done with a glucose value greater than or equal to 200 mg / dL (venous blood at any time).

4.2.1. *Definition of variables*

Let the following premises be identified by letters for formal representation:

- p : fasting blood glucose ≥ 126 mg / dL on two occasions
- q : OGTT glucose ≥ 200 mg / dL on two occasions
- r : glycosylated hemoglobin $\geq 6.5\%$
- s : random blood glucose levels ≥ 200 mg / dL in patients with symptoms of diabetes
- t : diagnosis of diabetes mellitus

4.2.2. *Logical formulation*

Considering each of the premises and the relationships that link them according to the statement, we proceed to write the formula that represents it, choosing the appropriate connective with the following results and using the symbol \vee as the OR operator:

$$(p \vee q \vee r \vee s) \rightarrow t \quad (3)$$

4.2.3. *Truth table*

The truth table resulting from formula (3) is similar to given in Table 1. As in the AMI example, we have also represented here all possible combinations of values taken by the variables, allowing to know in what cases the diagnosis was right or wrong.

4.2.4. *Particular case management and logic verification*

"As a physician, you are seeing an asymptomatic patient with a fasting blood glucose of 127 mg / dl, and after 20 days the test is repeated yielding a value of 132 mg / dL, and therefore you make diagnosis of Diabetes Mellitus". In this case, the logical formula is:

$$\{[(p \vee q \vee r \vee s) \rightarrow t] \wedge q\} \rightarrow t \quad (4)$$

The truth table for this case is similar to given in Table 2, the result of which is also a tautology. Therefore, we can say that the reasoning shown in the statement is valid, verifying the formal validity of the diagnostic criteria.

4.2.5. *Flowchart*

The flowchart for the diabetes mellitus diagnosis is included in Figure 2.

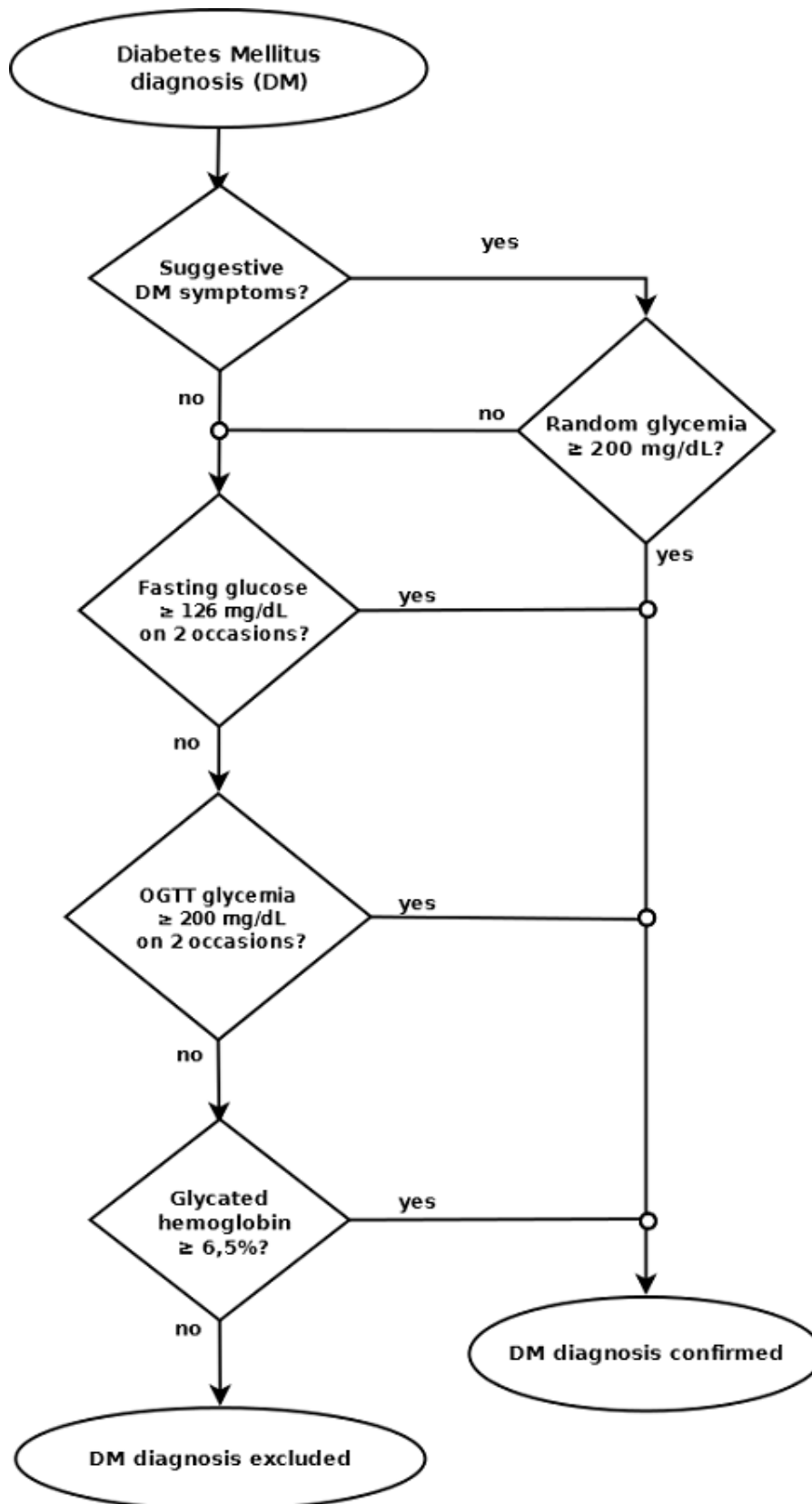


Figure 2 . Flowchart for Diabetes Mellitus (DM) diagnosis.

5. Problem of “missing data” in medicine

In medicine, formal logic can help unravel confusing situations. Unlike other branches, in this discipline complete information is rarely available and, for various reasons, there are missing key variables, which would otherwise help decision making. The lack of data or either unknown or uncertain information are elements to consider. The usual practice of omitting an information element (ignoring it when negative for instance), is unfortunately common in medicine. If on one hand it allows to save time, on the other hand it may be a source of error. The assimilation of the lack of data to negative data is common and formal logic tools can help prevent it.

Furthermore the uncritical adoption of logic in the medical reasoning with formulations based on two values (true or false) results in errors, false optimistic statistics and inappropriate public health decisions. It is sufficient to think about a mortality rate with missing data of death in dead individuals, resulting in rates lower than real, simply because unknown data is assimilated to subjects that are alive.

6. Medical teaching

Since 2014 we have developed a course called “Medical Informatics” intended for advanced medical students, with the aim to introduce them to the understanding and use of theoretical and technological informatics tools linked to their profession and to the interconnection of biomedical equipment with electronic medical records. Two of the first topics that are taught in this course are formal logic and algorithms (and flowcharts) as we believe it is one of the bases that Medical School Students should inevitably know before getting to understand the operation of any computer system that handles reasoning and logical inductions. As a result of teaching this course on three occasions we have learned how important it is to introduce the group of future physicians into the use of powerful tools for diagnosis and inference. Complementing important issues in medicine, medical informatics course supports teaching research and scientific method, so as to practice it daily with patients, to the benefit of less errors.

7. Error reduction

The availability of diagnostic protocols and standards in formal logic schemes allows to reduce mistakes, leaving fewer items to memory and relying on the ability of synthesis and deduction on formal grounds. Although the medical profession includes the function and ability to solve diagnostic and therapeutic strategies driving, the formal logic structures is a possible support with the resources of the information technology available. These resources, although they do not differ in their essence from traditional medical reasoning, allow the physician to work with a large number of variables, in a reproducible way.

8. Discussion and conclusion

Medical practice in the presence of abundant data and even more numerous standards, research and interrelationships, can hardly be exercised without the help of logical assistance tools that operate as mental "orthoses", strengthening the response capacity and reducing errors. This first approach involves the teaching of formal logic in the Medicine study plan. The first three groups of about a total of 60 students have resulted, in addition to their own training, in the conformation of a set of concepts to transmit to future generations of students. The observation of the profit that claim to have received, along with their increased operational capacity in programs and applications dedicated to clinical work, confirm that the road started should be perfected. It will be necessary however quantitatively assess the impact of this training in formal logic comparing somehow the performance of students so formed with those who didn't came to the training described here. The experience of other medical schools such as the Autonomous University of Mexico (UNAM) since 2010 points in the same direction [5] .

The rise of the expert systems (ES) developed in past decades [6] used extensively translating facts and logical chains based on "a priori" assumptions of medical diagnosis, logic that is included and encapsulated inside the ES. In this paper we propose instead the use of formal logic in medical training, as part of the conceptual tools for the use and development of diagnostic methods or deduction and setting up protocols on firm foundations. Either using computer systems or not attended practice of medicine. Because medicine can not be conceived in this historical moment away from the possibility of being benefited from the assistance of formal logic in proposals of increasing complexities, impossible to be solved by appealing to the simple memory of the professional.

In particular the complexity of certain diagnostic protocols with alternative associated treatments, arborescent with multiple variants, associated for example, to neonatal hypothermia therapy of hypoxic-ischemic encephalopathy of the newborn [4], are issues that will be addressed in this approach to reduce complexity and increase the rigor of its implementation. This can be achieved by the application of the methods of formal logic. We also see that by means of the rigorous application of protocols and documented observation of their results, they may deduct possible improvements and proposals for variants of treatment.

We call on readers to contribute ideas regarding the application of these methods to logical formalism, in view of its clinical adoption.

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