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Heterogeneous Methodology to Support the Early Diagnosis of Gestational Diabetes

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ABSTRACT Gestational diabetes mellitus (GDM) is a public health problem. Along with changes in eating habits, increased purchasing power, and climate change, among others, the number of women with gestational diabetes complicated by pregnancy is increasing. GDM generates problems for the mother and for the baby. Therefore, early diagnosis is important to indicate adequate medical follow-up and treatment in a timely manner. In this context, we present a hybrid methodology of a specialized system structured in the Bayesian networks, the multicriteria approach of decision support, and artificial intelligence. In such a methodology, input parameters are proposed in order to support the early diagnosis of GDM, based on the symptoms of diseases that manifest in concomitance or that develop due to the favorable environment caused by the evolution of undiagnosed diabetes. The diseases and symptoms studied were extracted from the medical literature. The diseases were weighted using the Bayesian networks, based on data from the Health Maintenance Organization with coverage in 11 Brazilian states. The weights of the symptoms were tabulated according to the analysis of medical specialists, organized by the multicriteria methodology, applying multiattribute utility theory (MAUT) methods, in particular, MACBETH, by using the Hiview computational tool. Finally, the information was structured in the knowledge base of a specialist system, made in Expert SINTA software.

INDEX TERMS Gestational diabetes, Bayesian network, multicriteria, expert system, MACBETH, Expert SINTA.

I. INTRODUCTION

The early diagnosis of diseases has great relevance to society because it is an ally in improving quality of people's life and in the generating of economic growth in the countries. This diagnosis makes it possible to initiate due treatment as early as possible, avoiding deaths [1], [2].

Diabetes Mellitus is a chronic metabolic disorder caused by absolute or relative lack of insulin [3].

According to [4], there are three major types of diabetes, namely:

- Diabetes Type 1: results from the destruction of Îš? cells, usually leading to an absolute insulin deficiency. It affects 5 % to 10 % of cases [5], [6];
- Diabetes Type 2: results from a progressive defect in insulin secretion due to insulin resistance. It affects 90 % to 95 % of cases [5], [6];
- Gestational Diabetes: the intolerance to carbohydrates of varying degrees of intensity, first diagnosed during pregnancy, and which may or may not persist after childbirth. Gestational Diabetes Mellitus (GDM) can progress to type 2 diabetes [6].

Gestational Diabetes Mellitus - GDM is a public health problem [7]. With the change in eating habits, increased purchasing power, climate change, among others, we can see the growth in the number of women who have complicated gestational diabetes [8].

GDM generates problems for the mother, such as pregnancy-induced hypertension and pre-eclampsia, cesarean delivery, polyhydramnios, type 2 diabetes and for the baby, as macrosomia, organomegaly, fetal hypoxia and respiratory distress syndrome in the newborn, hypoglycemia, polycythemia, hyperbilirubinemia, hypocalcemia, type 2 diabetes [9]–[11].

In the last decades, the study of the causes of this disease has undergone changes, including adjustments in

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the diagnosis and follow-up protocols, especially in more developed communities, partially due to miscegenation and obesity, among others [12].

The risk factors considered by the American Diabetes Association are [12]:

- age >= 25 years;
- overweight/obesity (Body Mass Index > 25 kg / m2);
- family history (first degree);
- history of altered glucose metabolism;
- obstetric history like gestational loss of repetition, GDM, polyhydramnio, fetal malformations;
- ethnicity: hispanic, asian, african, native american.

The Brazilian Society of Diabetes supplemented the list for risk factors during pregnancy for: excessive maternal weight gain, fetal macrosomia, polyhydramnios; the use of hyperglycemic drugs (corticosteroids, thiazide diuretics, among others); polycystic ovarian syndrome; and Metabolic syndrome: dyslipidemia, hypertension, insulin resistance [12].

The American Diabetes Association (ADA), American Council of Obstetricians and Gynecologists (ACOG), the World Health Organization (WHO), the International Diabetes Federation (IDF) and the International Association of Diabetes and Pregnancy Groups (IADPSG), agree with the protocol of using the anamnesis of the first prenatal visit to evaluate the risk of the patient for Gestational Diabetes and to submit it to an Oral Test of Glucose Tolerance Test (OGTT) after the 20th week gestation [13].

There are several protocols with criteria for the diagnosis of Gestational Diabetes (World Health Organization, Carpenter and Coustan, O'Sullivan), but the most recent was defined in 2010 by the International Association of Diabetes and Pregnancy Groups (IADPSG) in the study Hyperglycemia and Adverse Pregnancy Outcomes (HAPO). According to these criteria, the diagnosis of Gestational Diabetes is made if at least one of the blood plasma Glucose concentration values is greater than or equal to the thresholds of 92, 180 and 153mg / dl, respectively for fasting, one hour and two hours, after ingestion of solution 75 g of glucose - OGTT (Oral Glucose Tolerance Test), as shown in the Table 1 [13].

TABLE 1. Oral glucose tolerance test [13].

Organization	OGTT Glucose Ingestion	Fasting	1 hour	2 hours	3 hours
ADA	100 g	95	180	155	140
ACOG	100 g	105	190	165	145
WHO	75 g	126	–	140	–
IADPSG	75 g	92	180	153	–

To minimize the risk, it is necessary to diagnose GDM early, but the Oral Glucose Tolerance Test (GOTT) is inadequate in the first trimester of gestation, as pregnancy-induced hyperglycemia is not always evident [14].

Treatment for Gestational Diabetes consists of [15]:

- Diet;
- Physical exercises;
- Glycemic control;
- Insulin therapy;
- Performing childbirth.

In this context, this study aims to present a hybrid model capable of performing the early diagnosis of GDM based on the disease code, according to the International Registry of Diseases - ICD [16], analyzing the medical history of pregnant patients from the database of a health insurance company which covers eleven Brazilian states, from January 2004 to December 2009.

The article is structured as follows: Section 2 presents comorbidities to GDM and its symptoms; Section 3 lists some work related to GDM in the area of Computer Science; Section 4 prepares the data and applies the Bayesian Networks to identify the most relevant diseases; Section 5 describes the application of Multicriteria Decision Analysis - MCDA on the symptoms of selected diseases evaluated by physicians; Section 6 represents the knowledge, structured in rules of production and probability, in a specialist system that can assist health professionals in the early diagnosis of GDM; Section 7 presents the conclusions and possible future work.

II. COMORBIDITIES OF GESTATIONAL DIABETES

In the research conducted by [8] GDM was associated with other pathologies in 76.0% of pregnant women. In these circumstances, diseases that may occur concomitantly with Gestational Diabetes Mellitus or have their manifestation favored by their onset are described below:

- Threatened abortion and Hemorrhage in Pregnancy: GDM greatly affects the gestational environment, increasing in 3 times the congenital malformations and 10 times the preterm deliveries [17]; Some of the symptoms are bleeding; abdominal cramping; backache; anemia [21];
- Primary and Gestational Hypertension: the most prevalent pathology associated with GDM in 18.0 % in pregnant women [8]; its symptoms are defined as altered blood pressure, headache, dizziness, blurred vision [21];
- Abdominal and Pelvic Pain: with the advancement of gestational age, the lumbar and pelvic pains symptoms) become accentuated [18];
- Vagina and Vulva Infections and Inflammatory disease of cervix uteri: the general genital tract infection rates among the 200 women diagnosed with GDM were 68.5 %, in which 40 patients had at least two different infections, since GDM is an endocrine condition that can alter vaginal pH, allowing excessive growth of microorganisms that facilitate these infections [19]; some of the symptoms are mucopurulent discharge, fetid vaginal odor, dysuria, verruca, itch, burning and fever [21];
- Fetal Problems or Pregnancy-Related Conditions: according [20], GDM is associated with excessive growth in insulin-dependent tissues, generating macrosomia and increasing the predisposition to

perinatal alterations; gestational complications such as preeclampsia, polyhydramnios, operative problems and perinatal mortality; the fetal problems among pregnant women diagnosed with GD include hypoglycaemia with 48.6%, jaundice with 25.4%, macrosomia with 24.6%, prematurity with 19% of fetuses [11]; with symptoms of excessive or insufficient weight gain of the mother, pre-gestational overweight, fetal macrosomia [21];
- Cystitis: the most frequent complications in pregnant women with diabetes are the infections (22%), in which the urinary tract infection corresponds to 11.9% [11]; its symptoms are dysuria, frequent and and urgent urination, fever, hematuria, bladder pain and migraine [21].

This Section listed some diseases and their symptoms found in the literature associated with GDM.

III. GESTATIONAL DIABETES MELLITUS IN THE AREA OF APPLIED COMPUTER SCIENCE

This Section presents a collection of studies in the area of Computer Science linked to GDM.

The focus of the work performed by [22] was to improve the diagnosis of GDM from data mining techniques, resulting in experiments that show that random trees are more accurate and have a lower error rate.

As a way to analyzing the parameters of greatest influence in the definition of Diabetes diagnosis, [23] proposed a hybrid model for the creation of a Specialist System using Bayesian Networks, Multicriteria Methodologies of Decision Support and Artificial Intelligence, in which information such as age, practice of physical activity, smoking, alcohol and fruit / vegetable consumption, BMI are evaluated.

From the use of the neural network, [24] presented an Expert System responsible for diagnosing GDM.

In [25] a predictive model for diabetes diagnosis was constructed using SMOTE (Synthetic Minority Over-sampling Technique) and Decision Tree Classifier. The prognostic attributes are age, fasting blood sugar, prandial, waist measurement, BMI, systolic blood pressure, diastolic blood pressure, blood plasma glucose, patient's gender, and family history.

From the [26] study on GDM diagnosis, two models were implemented to compare Bayesian network and decision tree, which considered the attributes: number of pregnancies, glucose tolerance test, blood diastolic pressure, triceps skin fold thickness, serum insulin, BMI Body Mass Index, prediction of diabetes (genetics) and age. The result indicates that Baysean networks are more accurate.

In [27], it was used naive bayes with genetic algorithms in his work, resulting in the selection of the attributes: glucose tolerance test, serum insulin, BMI and age of the patient.

In order to diagnose diabetes early, [28] used the Decision Tree, Support Vector Machine and Naive Bayes classification algorithms, which yielded an accuracy of 73.82%, 65.10% and 76.30%, respectively.

The [29] proposal of a GDM classifier based on Bayesian networks found accuracy of 99.51 % confirming that the technique is promising.

Finally, [30] made use of the Support Vector Machine for the diagnosis of diabetes, from the selection of a set of variables that would produce the best classification of individuals. Family history, age, race and ethnicity, weight, height, waist length, BMI, and hypertension were chosen for the diabetes diagnosed or undiagnosed vs pre-diabetes or non-diabetes, and gender and physical activity for the undiagnosed diabetes or pre-diabetes vs non-diabetes.

This Section presented a brief description of some studies carried out in the area of Computer Science linked to GDM.

IV. APPLICATION OF BAYESIAN NETWORKS IN THE DIAGNOSIS OF GDM

Bayesian networks are useful when it is necessary to work with the uncertainty and they are widely applied when it is necessary to work in complex domains, such as in the area of health [23]. When studying chance and solving a problem with insufficient and imprecise information it is appropriate to use probability techniques, such as the Bayes rules [31].

Probability can be qualified as conditional, when it depends on an earlier condition, and unconditional, which is the probability of something occurring when dealing with chance or lack of information. And making use of a conditional probability and two unconditionalcan be applied the theorem of Bayes, according to equation 1.

$$P(B|A) = \frac{P(A|B) \times P(B)}{P(A)} \tag{1}$$

Information was collected from the medical care of pregnant patients, from a database of a health plan operator, with coverage in eleven states in Brazil.The code of the disease of the patient, according to the ICD - International Registry of Diseases, version 10 was used as reference and input of the study of all the consultations that possessed this information registered in the medical care guide (for payment / administrative expenses), from January 2004 to December 2009. The ICD is the basis for the identification of health trends and statistics in the world, and the standard for registering diseases and health conditions, according to ICD [16].

The information was organized into two groups, one with a positive diagnosis for GDM, of pregnant patients with a record of one of the events of ICD 10 - O24 Diabetes Mellitus during gestation, ICD 10 - O24.4 Diabetes mellitus arising during pregnancy and ICD 10 - O24.9 Diabetes mellitus in pregnancy, unspecified, excluding ICDs associated with existing previous diabetes; and the negative diagnosis for GDM of pregnant patients who have a record of one of the ICD events of parturition and have no diabetes-related ICDs.

Among the 1580 pregnant women analyzed, 255 were diagnosed with GDM and one of the 10 most frequent ICDs selected by the study. The list of ICDs; the number of concomitants to GDM (NC); probability of incidence (PI); posterior probability of a patient having GDM (PP) based on the

TABLE 2. Pregnant women with the most frequent diseases and with GDM.

ICD	Description	NC	PI	PP	ND
O20.0	Threatened abortion	69	0.270588	0.188011	35.530800
O20.9	Hemorrhage of early pregnancy, unspecified	67	0.262745	0.265873	66.518700
I10	Essential hypertension (primary)	51	0.200000	0.196911	39,073000
O36.9	Maternal care for fetal problem, unspecified	49	0.192157	0.350000	100.000000
N72	Inflammatory disease of cervix uteri	45	0.176471	0.151006	20.803679
R10.4	Unspecified abdominal pain	39	0.152941	0.098734	0.000000
N76.8	Other specified inflammation of vagina and vulva	39	0.152941	0.161157	24.843350
O13	Gestational [pregnancy-induced] hypertension without significant proteinuria	39	0.152941	0.278571	71.572508
O26.9	Pregnancy related conditions, unspecified	34	0.133333	0.165049	26.392116
N30.9	Cystitis, unspecified	26	0.101961	0.168831	27.897543

existence of comorbidities, result of the application of the Bayes rules; as well as these normalized data (ND), changing the scale of values from 0 to 100, are shown in the Table 2.

The diseases associated with GDM indicated by the literature, coroborated by a database, were collected to identify the posterior probability of a pregnant woman to have undiagnosed GDM, based on the diagnosis of the selected comorbidities, applying the bayes rule. Finally, the result was normalized on a scale of 0 to 100.

V. APPLICATION OF MULTICRITERIA DECISION ANALYSIS IN THE DIAGNOSIS OF GDM

In this Section we will present the use of MCDA in the hybrid model proposed for the diagnosis of GDM.

MCDA is a specific perspective to deal with decision problems, in situations where there is a need to establish priorities, considering a multiplicity of criteria. These criteria are used for decision-making, a complex activity due to the choice made in the face of possible alternatives of action, diversity of judgment and ways of evaluating this diversity, and in some cases complexity is also due to conflicts of interests of decision makers.

On the preferences applied, the alternatives are based on four relations, namely: indifference (there is reason for indifference in the choice between two alternatives); strict preference (there is reason for one alternative to be more favored than another alternative); weak preference (there are doubts about favoring alternatives); incomparability: there is no application of any of the above.

This process can be divided into three phases: structuring, evaluation, and recommendation; and steps: characterization of the decision context, definition of rejection and evaluation criteria, construction of impact descriptors, determination of relative weights or value scales cardinal, impact analysis and partial evaluation of the criteria, calculation of global value, through an additive aggregation model and desensibility and robustness analysis of the results [32].

When dealing with the types of multicriteria approach, the Multiattribute Utility Theory (MAUT) admits that in a decision making process all comparisons between alternatives are possible. The MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) multicriteria method is an example of MAUT application [32].

The MACBETH requires a qualitative judgment, based on a scale of value, on the differences in attractiveness of the criteria. This attractiveness is defined as the difference between the relevance of two criteria, whatever the context of a decision.

To facilitate the handling of the concepts of the MACBETH method, the HIVIEW tool (version 3.2.0.4, manufactured by Catalyze Ltd) was used, which implements the M-MACBETH software. HIVIEW was the application chosen to generate the problem judgment matrices, to carry out several analyzes of sensitivity and robustness of the model results, offering numerous graphical representations that facilitate the elaboration of a report justifying the elaborated recommendations. In addition, HIVIEW provides decision makers with confirmation of their judgments, allowing them to change some values that are not in line with their expectations, validating the data model and consolidating its credibility.

Considering the phases of implementation of the MCDA, the research will:

- Structuring Phase: the comorbidities that can affect pregnant women with GDM and their symptoms will be identified and organized, according to the medical literature, as well as the validation of the survey done, according to experts.
- Evaluation Phase: the weights made by the doctors about each symptom / disease and the organization of the value judgment matrix and other elements of the methodology will be listed.
- Recommendation Phase: the organization of the data according to MACBETH and the partial results that will be used in the construction of the Expert System will be detailed.

A. STRUCTURING PHASE

For each of the most frequent diseases that can occur concomitantly to GDM, mentioned in the Table 2, we collected

TABLE 3. Symptoms of diseases concomitant to GDM, validated by medical.

Symptom X Disease	Threatened abortion	Hemorrhage in pregnancy	Hypertension	Maternal care for fetal problem	Inflammatory disease of cervix uteri	Abdominal and pelvic pain	Inflammations of the vagina and vulva	Gestational hypertension	Pregnancy related conditions	Cystitis
SGVG - Vaginal bleeding	100	100	0	0	0	70	0	0	0	33
CLUT - Uterine colic	83	0	0	0	0	100	0	0	0	0
PRAR - Altered blood pressure	22	27	90	0	0	0	0	90	0	0
DCAB - Headache	0	45	100	0	0	0	0	100	0	50
TONT - Dizziness	0	23	90	0	0	0	0	90	0	0
TURV - Blurred vision	0	30	80	0	0	0	0	80	0	0
EDEM - Edema or swelling throughout the body	0	0	43	0	0	0	0	60	0	0
SECR - Mucopurulent secretion	47	0	0	0	100	0	100	0	0	0
DPEL - Pelvic pain	23	0	0	0	70	90	0	0	0	0
NAUS - Nausea	0	7	67	0	40	7	0	80	0	0
IVUL - Irritation of the vulva	0	0	0	0	0	0	47	0	0	0
ODOR - Fetid Vaginal Odor	0	0	0	0	43	0	70	0	0	0
PRUR - Vulvar pruritus	0	0	0	0	0	0	40	0	0	0
LVER - Injury, Cancer, or Wart	0	0	0	0	27	0	90	0	0	0
URIN - Urinary frequency and urgency	0	0	0	0	0	0	0	0	0	80
DSUP - Supra-pubic discomfort	0	0	0	0	0	13	0	0	0	80
FEBR - Fever	0	0	0	0	40	0	40	0	0	53
DBEX - Pain in the bladder	0	0	0	0	0	0	0	0	0	73
VULV - Vulvodynia or stinging while urinating	0	0	0	0	0	0	90	0	0	80
PEXC - Excessive Weight Gain	0	0	0	80	0	0	0	0	80	0
PINS - Insufficient weight gain	70	0	0	33	0	0	0	0	80	0
CIRC - Excessive abdominal circumference	0	0	20	70	0	0	0	20	47	0
AUME - Uterine height alteration	0	0	0	57	0	0	0	0	23	0

the possible symptoms pointed out by the medical literature. These data were presented to three physicians, being one specialized in Obstetrics and two specialized in General Practice. Referenced physicians related some symptoms and evaluated the impacts of these symptoms in the diagnosis of the disease related to this study, as shown in the Table 3.

Where attractiveness is the difference between the relevance of any two criteria in the context of a decision.

TABLE 4. Scale of attractiveness defined model.

Value	Description	Initial Value (%)	Final Value (%)
6	Extreme	83.34	$+\ infty$
5	Very Strong	66.68	83.33
4	Strong	50.01	66.67
3	Moderate	33.34	50.00
2	Weak	16.68	33.33
1	Very Weak	0.01	16.67
0	Null or Inexistent	$-\ infty$	0.00

In the present study the attractiveness was evaluated, given $c1$ and $c2$:

- if none of the criteria is relevant in the analysis, the attractiveness is said to be 0-Null;
- if any of them are relevant in the analysis, but not both, it is said that the attractiveness is P-Positive;
- if both are relevant in the analysis, the attractiveness is attributed by the module of the difference of relevance between them, that is, $|c1 - c2|$. If the difference is zero, then it is considered Null attractiveness, otherwise it is considered one of the constant values in the Table 4, whose scale was divided into fractions of 6 (0.016666).

B. EVALUATION PHASE

The tree shown in Figure 1 was generated using the HIVIEW tool and presents an illustrated summary of all the diseases that will be worked upon.

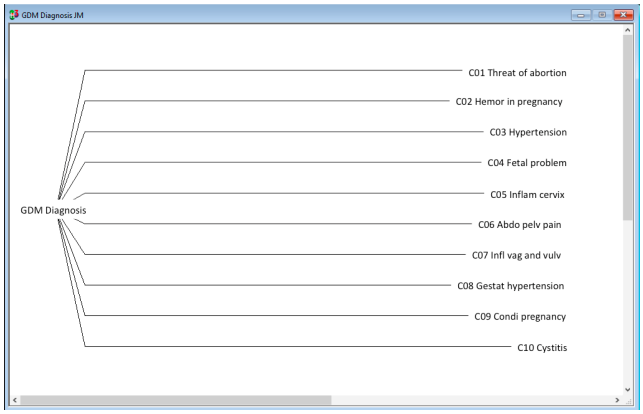

FIGURE 1. Gestational diabetes - Graphical representation of the model.

Each disease was assigned a code consisting of the letter C and two digits for ease of reference. Each disease referred to in this Figure will have a diagnosis proposal with the help of MACBETH software.

In this context, with data from the Table 2, one can generate the Table 5 with the difference in attractiveness between each pair of diseases.

The filling of the judgment of value matrix for Diseases based on Table 5 can be seen in Figure 2, as well as the respective values calculated by MACBETH from the judgments.

After processing the value judgment matrix, it is possible to analyze the sensitivity of the generated data, using the Figure 3, better known as Thermometer.

TABLE 5. Normalization of bayes' theorem applied to the most relevant diseases.

Diseases	C04	C08	C02	C03	C01	C10	C09	C07	C05	C06
C04	0	28	33	61	64	72	74	75	79	100
C08		0	5	32	36	44	45	47	51	75
C02			0	27	31	39	40	42	46	67
C03				0	4	11	13	14	18	39
C01					0	8	9	11	15	36
C10						0	2	3	7	28
C09							0	2	6	26
C07								0	4	25
C05									0	21
C06										0

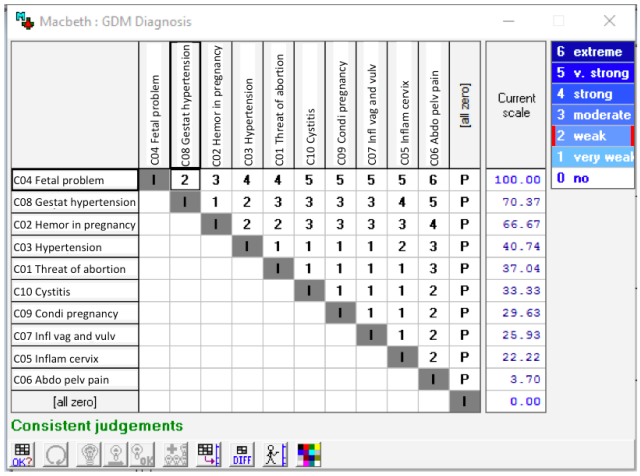

FIGURE 2. Gestational diabetes - Trial matrix.

C. RECOMMENDATION PHASE

Figure 4 consolidates all information fed into HIVIEW (software for structuring the multicriteria model) and processed by MacBeth. It also shows the weight of each disease in relation to the others, and indicates the impact of each disease symptom in the diagnosis of this disease, as well as the contribution to the Diagnosis of GDM.

According to Figure 4, the most relevant diseases of the model are: C04-Fetal problem, C08-Gestational Hypertension and C02-Hemorrhage in pregnancy, with weights, 100, 70 and 66, respectively. It can also be inferred that the most important symptoms of the model are: DCAB-Headache, PEXC-Excessive Weight, PRAR-Altered blood pressure, CIRC-Excessive Abdominal Circumference, TONT-Dizziness, TURV-Blurred vision, SGVG-Vaginal bleeding, NAUS-Nausea, ALUT = Uterine Height and SECR-Mucopurulent Secretion, respectively, with weights: 37, 30, 29, 26, 26, 26, 25, 21, 15, 15.

This Section presents the evaluation of the diseases and symptoms obtained in the literature and its application in the tool Hiview, which implements the MACBETH methodology, calculating the weight of each disease in relation to the others, and the impact of each symptom of the disease in its diagnosis, as well as their contribution to the diagnosis of GDM.

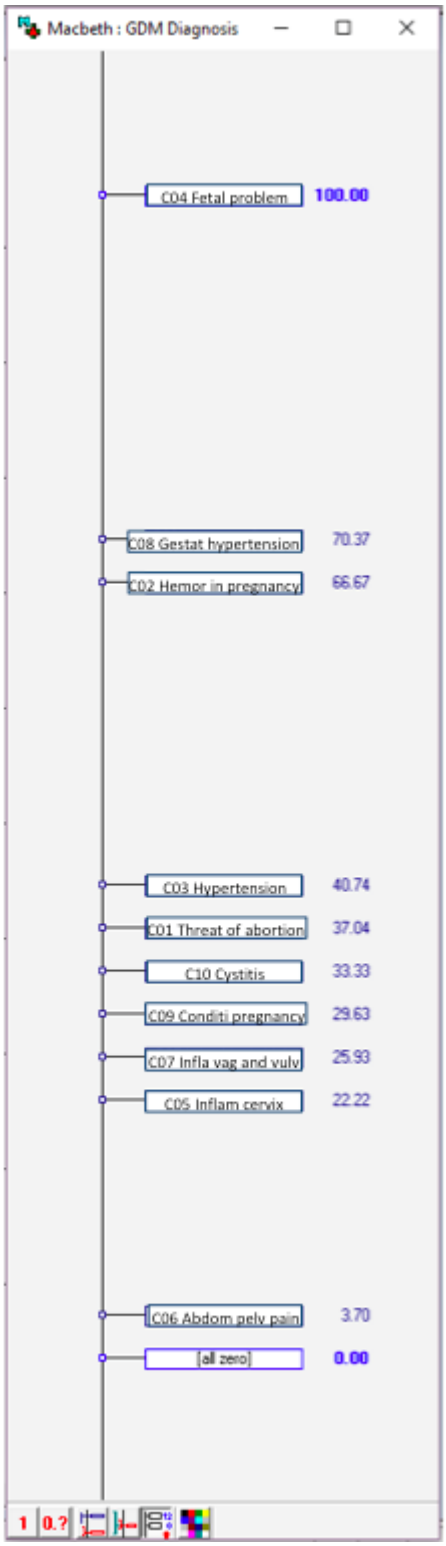

FIGURE 3. Gestational diabetes - Thermometer.

VI. APPLICATION OF EXPERT SYSTEM IN THE DIAGNOSIS OF GDM

This Section demonstrates the use of an Expert System - SE applied for the diagnosis of GDM. The tool chosen was the

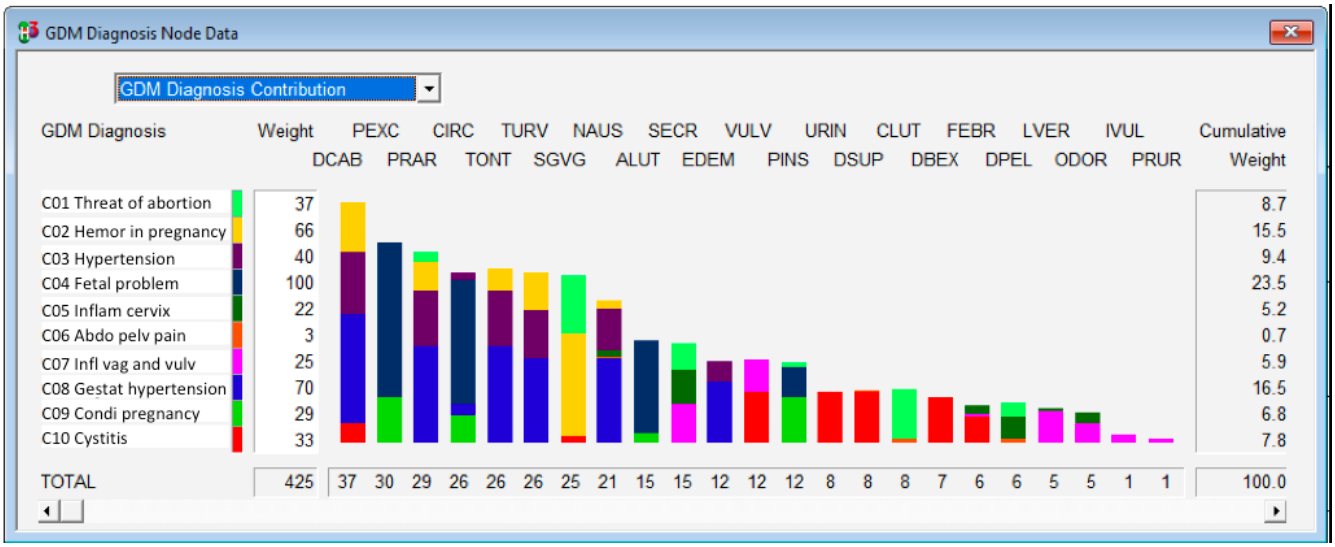

FIGURE 4. Gestational diabetes - Symptom and disease.

Expert SINTA due to its modularity, inductive editing and transparency [33].

ExpertSINTA is a computational tool that applies Artificial Intelligence techniques for automatic generation of expert systems, using a knowledge representation model based on production rules and probabilities. This tool has a shared inference machine, which enables the automatic construction of menus, screens, and the probabilistic treatment of production rules. The user responds to a sequence of questions presented by the expert system, which, after inferences, fits the answers in the context pointed out by the user.

The steps followed for the construction of the Knowledge Base are detailed below:

1) Definition of Variables;
2) Definition of Objectives;
3) Definition of Interfaces;
4) Definition of the Rules;
5) Execution of the Specialist System.

A. DEFINITION OF VARIABLES

The first step of the Expert SINTA is to provide the Knowledge Base with the variables that will be used for processing. All variables, including those that the user will not interact directly with, but that can be used for intermediate processing must be registered; and those in which the final results, or objectives, will be stored.

Variables can be Numeric, Multivalued, or Univalued. In the case of a variable being binary, that is, having as domain only the values 1 or 0, True or False, or Yes or No, it will be considered Univalent and the register of its domain of values can be omitted, being considered the values 'Yes or no'. It is worth mentioning that in case the value assignment is omitted, the value 'Unknown' will be assigned to the variable.

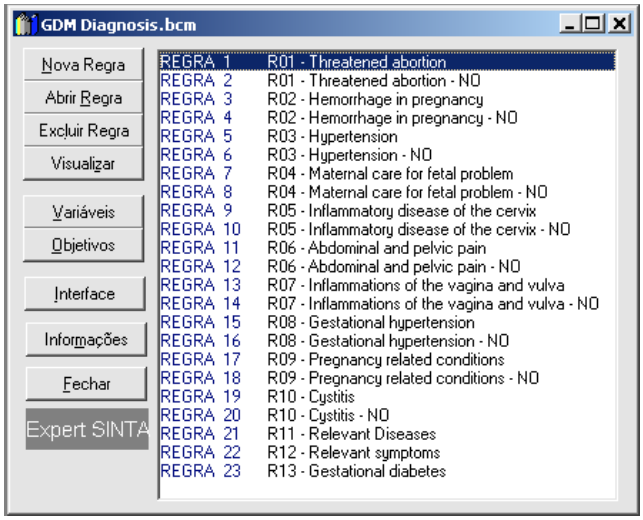

FIGURE 5. Expert SINTA - Rules register.

B. DEFINITION OF OBJECTIVES

The next step in creating the variables is to define which variables will be used as the Goal Variable. The Goal Variable stores the result of some system processing (Rule). Even if the variable is only applied for intermediate processing, that is, it is not necessary to display the value to the user during execution, it must be defined as Goal Variable.

C. DEFINITION OF INTERFACES

After registering the variables and determining which ones are considered Objective type, one must establish how the user should interact with the system, defining which variables have linked questions.

To assist the user of the system it is possible to register a small text with the Reason or Help. There is also a flag

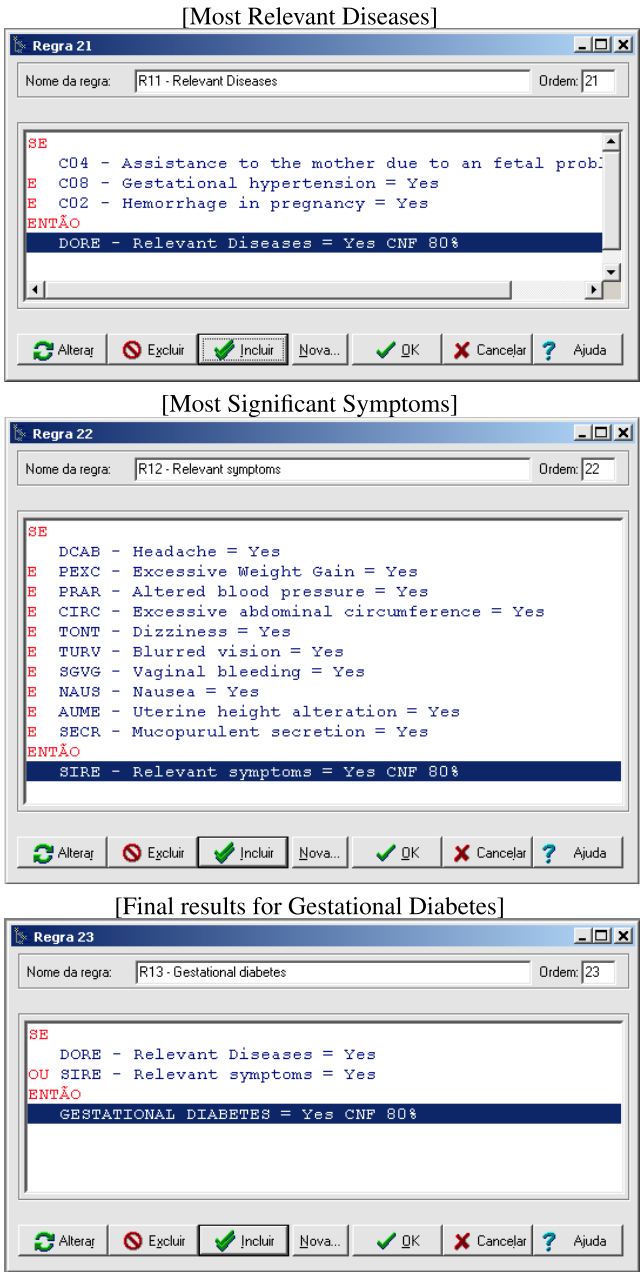

FIGURE 6. Final results for gestational diabetes. (a) Most relevant diseases. (b) Most significant symptoms. (c) Final results for gestational diabetes.

available to indicate whether the user should be allowed to fill the confidence level for the response.

D. DEFINITION OF THE RULES

The next step is to define the rules of the system. The rule tells the Expert SINTA engine how to evaluate each response, or set of responses, to infer the value of a variable, or set of variables. In the same way that several variables can interact for the result of a variable, the evaluation of a variable or set of variables can sensitize a variable or set of variables.

The more rules the more the system will be specialized and able to make inferences within its domain. In this context,

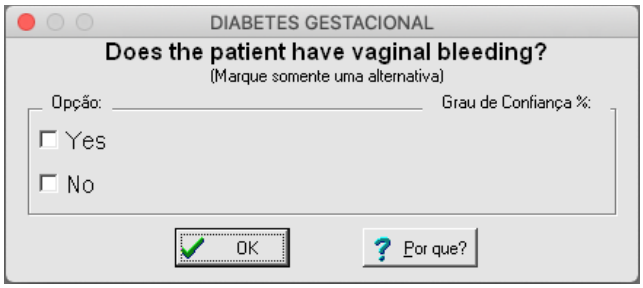

FIGURE 7. Expert SINTA - Inquiring the system user.

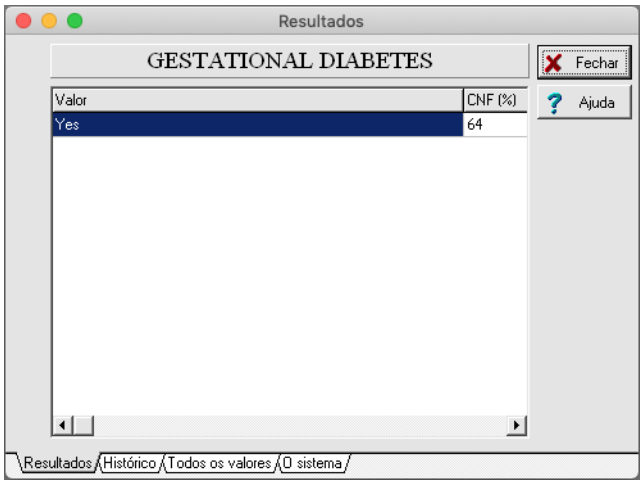

FIGURE 8. Expert SINTA - System especialist result.

23 rules were registered for the diagnosis of GDM, Figure 5. For each disease, two rules were registered, one for a positive diagnosis and one for a negative diagnosis. At the end, three rules for positive diagnosis of Diabetes were registered: the first one evaluating the diseases which are relevant to GDM, the second one evaluating the symptoms which are relevant to GDM and a third one that evaluates the first two for the final diagnosis of the disease.

It should be noted that the rules are created in the IF-THEN format; however, it should not be confused with the IF-THEN-ELSE format, which is very common in the implementation of computational logic evaluations, since the latter is not present in the formation of Expert SINTA rules.

For the positive GDM test to be inferred, the occurrence, concurrently or separately, of the most relevant diseases or the most relevant symptoms, with a confidence level of 80 %, must be true, according to Figures 6.

E. EXECUTION OF THE SPECIALIST SYSTEM

At the beginning of Knowledge Base processing, all questions regarding the variables are displayed, and in the order in which the Rules were defined. If the user does not understand the reason for the questioning, they can solve the doubt in the same interface. An example of a form with question can be seen in Figure 7.

After answering all previously registered questions, the Expert SINTA engine processes the rules, produces and

displays the result, according to Figure 8, as well as the history of the processing of the rules, the status of all the variables reported by the user, the target variables and all the rules registered in the Knowledge Base.

This Section detailed the construction of a specialist system for the purpose of diagnosis of Gestational Diabetes. The Exper SINTA software was highlighted, using as input to the SE the diseases and symptoms discussed throughout the present work. It is noticeable that the creation of well-structured rules is decisive for the construction of a robust and efficient system.

VII. CONCLUSION AND FUTURE WORK

Gestational Diabetes Mellitus - GDM is a public health problem that needs rapid diagnosis, to avoid negative risks for the mother and the fetus. Current medical protocols using Oral Glucose Tolerance Test - OGTT are not feasible in the first months of gestation, highlighting the need for new options.

This work presented the methodologies and detailed the steps for the structuring of a hybrid approach capable of supporting the early diagnosis of GDM. The proposal combines concepts of Bayesian Networks, Multicriteria Analysis and Expert Systems.

It was possible to observe that the items on the list of comorbidities of GDM found in the medical literature were identified as having the highest incidence in the database of a Health Plans operator, with coverage in eleven Brazilian states.

The MCDA methodology, in turn, was applied to structure the diseases and symptoms of comorbidities to DMG. Thus, the weight of each disease was calculated in relation to the others, as well as the impact of each disease symptom on its diagnosis and on the diagnosis of GDM. Therefore, MACBETH supported the tabulation of symptom weights made by specialist physicians in matrices structured by value and for each disease, revealing the importance of the symptoms and their intersection between diseases.

As for the Expert System, it was used to organize all information produced in a knowledge bank so that it could infer the occurrence of GDM within reasonable confidence.

At this juncture, the Expert SINTA tool provides easy-to-manipulate forms, with mechanisms of knowledge production, through the use of Artificial Intelligence, allowing the receiving of information and supporting the diagnosis of GDM by non-medical professionals. In this tool it is possible to register rules to support the diagnosis; and the quality of the result can be improved by increasing the number of rules, thus expanding the system's specialization and the ability to run on its domain.

It should be noted that the information provided by this study does not exclude the follow-up and diagnosis of a medical professional.

As future work we suggest:

- Integrate the proposed hybrid model into a single computational tool;
- Provide the structured model for the public health network, adapting it to mobile platforms. Thus, it could cover remote areas of the country, improving the prenatal consultation protocol, and therefore the health of the mother and the fetus;
- Use other databases to obtain the relevance of the diseases, in which recalibrating the weights would allow the improvement of the final result of the model.

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