Ontology-based decision support system for dietary recommendations for type 2 *diabetes mellitus*

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Abstract. Decision support systems (DSS) play an increasingly important role in medical practice. By assisting physicians in making clinical decisions and subsequent recommendations, medical DSS are expected to improve the quality of healthcare. The role of DSS in diabetes treatment and in particular in post clinical treatment by organizing an improved regime of food balance and patient diets is the target area of the study. Based on the Diabetes Mellitus Treatment Ontology (DMTO), the developed DSS for dietary recommendations for patients with diabetes mellitus is aimed at improvement of patient care. Having into account the clinical history and the lab test profiles of the patients, these diet recommendations are automatically inferred using the DMTO subontologies for patient's lifestyle improvement and are based on reasoning on a set of newly developed production rules and the data from the patients records. The research presented in the paper is focused at intelligent integration of all data related to a particular patient and reasoning on them in order to generate personalized diet recommendations. A special-purpose knowledge base has been created, which enriches the DMTO with a set of original production rules and supports the elaboration of broader and more precise personalized dietary recommendations in the scope of the electronic health record services.

Keywords: decision support system, semantic interoperability, knowledge base, ontology, type 2 diabetes mellitus, diet recommendation

1 Introduction

Medical decision support systems and other intelligent applications in bio-medical practice and research depend on increasing amounts of digital information. Intelligent data integration in the biomedical domain is concerned as an instrument for combining data from different sources, creating a unified view and new knowledge as well as improving their interoperability and accessibility to a potential user [1]. Knowledge bases and in particular formal ontologies are being used to describe and organize shared biomedical knowledge [2]. Semantic interoperability is considered as important for a number of healthcare activities including quality improvement programs, population health

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DOI: 10.1007/978-3-030-77967-2_61

management and data management and is of great significance in electronic health records (EHR) information systems and their various services.

The major aim of this study is to develop a knowledge-based DSS for dietary recommendations for diabetes mellitus type 2. The principal tasks of the work are related to the intelligent integration of patient lab test, clinical data and food specifications aiming at development of automatically generated suggestions of a well-defined personal diet plan based on these data. The knowledge base is created using DMTO [4] and a set of related production rules defined specifically for the case. The main functionality of the inference engine is to generate an individual diet plan for each patient and to suggest some variants of particular menus covering this diet plan.

2 Problem description

Patient centered DSS. A properly designed DSS is an interactive software system intended to help decision makers to integrate useful information from a combination of raw data, documents, and personal knowledge, or business models to identify and solve problems and make decisions. Ontologies can add more power to clinical DSSs. An ontology can support knowledge sharing, easy maintenance, information integration and reuse in similar domains. The usage of production rules provides the differentiation of an extra layer of expert knowledge.

Diabetes mellitus application. Diabetes mellitus (DM) is a dangerous, complex, socially important chronic disease [4,5]. Type 1 diabetes mellitus (T1DM) can only be treated with insulin, whereas patients with type 2 diabetes mellitus (T2DM, 90-95 % of the cases) have a wide range of therapeutic options available, including lifestyle changes (mainly diet and food intake profile) and administration of multiple oral and/or injectable anti-diabetes drugs, including insulin.

DMTO creates a complete and consistent environment by enabling formal representation and integration of knowledge about treatment drugs, foods, education, lifestyle modifications, drug interactions, the patient profile, the patient's current conditions, and temporal aspects. DMTO introduces interesting features for T2DM treatment plans, and is expected to play a significant role in implementing intelligent, mobile, interoperable, and distributed DSS in diabetes therapies and post-clinical care [3].

The application of DSS in diabetes mellitus therapy has various examples including medicinal treatment, clinical survey of the patients, remote control and different levels of advising. The problems with post clinical activities, mainly the diet and lifestyle set of problems emerges as an important and challenging area. Our study is devoted mainly to this specific circle of problems related to the normal food intake considering specific diet requirements directly related to the patient personal ambulatory test profile.

3 Suggested methodology

Conceptual design. The applied methodology for developing the suggested ontology-based DSS is based on our conceptual model [6] of patient centered advising system

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for diet recommendations for T2DM. The system is with non-direct physician interaction for diet recommendation and utilizes a subject knowledge base which is implemented using DMTO and relevant production rules. DMTO provides the highest coverage and the most complete picture of coded knowledge about T2DM patients' current conditions, previous profiles, and T2DM-related aspects, including complications, symptoms, lab tests, interactions, treatment plan and diet frameworks, and glucose-related diseases and medications. The specific feature of the developed system could be related also to data integration between different clinical sources, food data and patient profiles.

Data flow. As the designed ontology-based diet recommendation system is a patient-centered one, the main data comes from the patient medical records and in particular from the clinical laboratory tests (Fig. 1). Personal data protection and all related ethical issues are considered in the system. Data can also be integrated from non-clinical sources including the general practitioner and other medical diagnostic sources. The data normalization part of the system includes formatting and cleaning of the non-sense outliers in the data. Each import of patient data contains the patient's profile and all lab tests related to it. In addition to this information, a treatment plan, including lifestyle subplan and diet is created. As a result of appropriate reasoning, the amounts and proportions for macronutrients for each meal are set. Another part of the data flow in the system comes from the food specificity sources – here we use aside with the DMTO related libraries, also external sources such as US Food Data Central[1].

A structured model for patient's clinical lab test data is defined in the disease history record as part of the hospital record for each patient, holding information for example about glucose, glycated hemoglobin, cholesterol and uric acid.

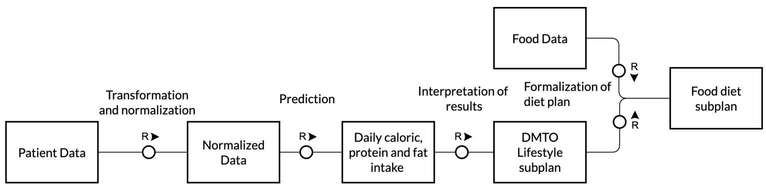

Fig. 1. System data flow

4 System architecture

The suggested system consists of the following parts (Fig. 2): an input part (patient data, food data), a user integration point with RESTFul API service, a subsequent data integrator, a knowledge base and corresponding inference engine, and a storage part including: diet recommendations cache, food data storage and patient instance base. The user integration endpoint server is designed for the purposes of data integration, data normalization and interface development and application. The input part is based

[1]https://fdc.nal.usda.gov/faq.html

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DOI: 10.1007/978-3-030-77967-2_61

on patient-centered data and some necessary food data for generating diet recommendations. The model for patient's data is determined on the medical laboratory check and the disease history as a part of the patient's health record. These patient data include all information from the laboratory tests, and its major components as glycated hemoglobin, glucose, cholesterol, uric acid. Patient data is used to create instances for the instance base. Food data comprises different geographic origin and energetic content for creating instances.

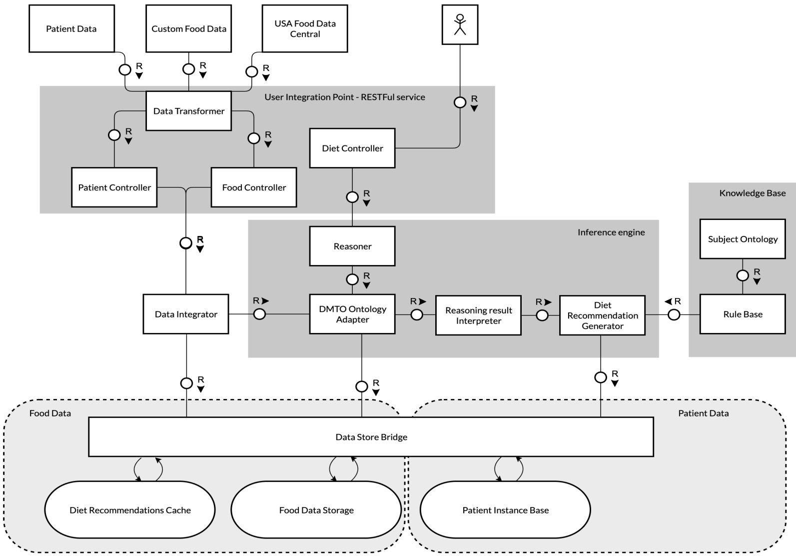

Fig. 2. Functional architecture of the system

The main component of our DSS for diet recommendations is the subject knowledge base, the core of which is DMTO. More precisely, the knowledge base of the DSS consists of two main parts an extendable copy of DMTO and a set of production rules (implemented in SWRL) describing specific knowledge for data analysis and decision making. The system has an application interface – server endpoints allowing the user to import patient data. Lab tests are linked with the patient profile via the property has_lab_test of the corresponding patient profile entity. When the ambulatory records are imported, the changes are saved and the generated IDs of all new patient profiles are returned.

The "heart" of the system is the inference engine, whose major function is the generation of diet recommendations based on the use of the knowledge of DMTO and decision-making rules. By processing a query for a patient diet suggestion, the server calls an appropriate reasoner which analyses the available data, performs suitable forms of inference (mainly forward checking) and generates a solution (Fig. 2).

A major contribution of this study is an appropriate extension of the DMTO by developing a model of DSS for dietary recommendations for T2DM. The first and most important patient specific modification is changing the data type from RDF/XML to

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OWL/XML, in order to be able to create has_lifestyle_participant and has_(certain)_meal object properties. RDF/XML is a serialization syntax for RDF graphs. OWL/XML is a serialization syntax for the OWL 2 Structural Specification. RDF/XML ontologies could not be represented properly using standard XML tools.

The entity has_lifestyle_participant is an object property of the type diet. This property is owned by lifestyle subplan. has_(certain)_meal (breakfast for example) is an object property (breakfast for example) of type meal. It is owned by the diet class. These properties are essential for building the chain treatment plan – lifestyle subplan – diet – meal. A next significant modification is related to the extension of the "patient profile" to have more than one lab test.

In order to achieve a personalized diet, different proportions between fat, carbohydrates and proteins are set for each meal. For a healthy person with values for "total cholesterol" and "fasting plasma glucose" (FPG or Glucose) and "urine blood" (Uric Acid) in normal intervals, the proportions are fat 30%, carbohydrates 50% and proteins 20%. For a person with values out of norm – the proportions are fat 20%, carbohydrates 40% and proteins 40%, raising protein amount and lowering carbs and fats (Table 1). To identify if a patient has lab test results within the normal ranges or out of normal ranges, a set of rules are defined which check that and also set the required ratio between fat, proteins and carbohydrates according to the lab tests results. The ratio between fat, carbs and proteins is set for the particular meal of the diet for the patient. The improved lab test contains some elements representing a set of blood lab tests – total cholesterol, glucose and uric acid. In addition to its value, a lab test element has also the attributes min-threshold and max- threshold giving information about the range of its value.

Table 1. Ranges of blood lab tests.

Parameter	Measure unit	Min. threshold	Max. threshold
Glucose	mmol/l	3.3	6.2
Glycated hemoglobin	%	5.7	6.5
Total cholesterol	mmol/l	0	5.2
Uric acid	umol/l	208	428

5 Results and discussion

To check whether a patient has lab test results within the normal ranges or out of normal ranges, a set of rules are defined. Rules are also set to meet the corresponding ratio between fat, proteins and carbohydrates according to the lab tests results.

The system initializes, integrates and gives values to the particular patient profile elements: patient plans (treatment, lifestyle, diet), patient total calories, total cholesterol lab test, FPG lab test, and diet referred to an example of a breakfast meal.

There is a check if these lab test values are in normal range or out of normal range. The normal proportions between carbs, fats and proteins are set up as follows 0.5, 0.3 and 0.2. Then the amounts of both calories and grams of a certain meal are calculated. The number of calories for a certain meal is calculated from the total calories multiplied

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DOI: 10.1007/978-3-030-77967-2_61

by the proportion of macronutrients for the whole meal. The weight [grams] is calculated using the number of calories. The reasoning procedure uses all available patient data. The reasoner executes rules by setting proportions of the macronutrients. There is a rule for each lab test checking its values testing for belonging to the normal range. The total number of calories for a breakfast meal, for example, is calculated on the base of the total calories from the patient profile. The quantity per macronutrient is based on the calculated proportions.

Our first operation example of the system is based on importing patient data with lab tests in norm. An amount of 1700 total calories is set as a referent patient profile. The patient profile includes laboratory tests as: FPG – 4 mmol/l, total cholesterol – 5 mmol/l and uric acid – 379 umol/l. A treatment plan is created for the patient profile, including a lifestyle subplan, where a set of diets for breakfast is suggested.

The reasoner executes the rules setting the proportions for the macronutrients. There is a production (SWRL) rule for each type of lab test checking if its value is in the normal range. Rules are setting the following properties of a meal in the diet: calories – "carbohydrate per meal", "fat per meal", "protein per meal"; quantity – "carbohydrate grams", "fat grams" and "protein grams".

The total calories for the breakfast meal are calculated from the total calories from the patient profile as 1700 * 0.25 = 425. All values for the lab tests are in norm and consequently the proportions between the macronutrients are set to normal – 50% carbs, 30% fats, 20% proteins. The exact calories and amounts calculated after the reasoning for each macronutrient can be seen in Table 2 (first row).

Other tests of our DSS are based on patient data out of norm. The total calories are again 1700. We imported data of a few patients with different lab tests exceeding the normal range. One patient has total cholesterol – 6 mmol/l, another patient has FPG – 10.13 mmol/l and the last patient has urine acid – 500 umol/l. For each of these patients the proportions between the macronutrients are set to 40% carbs, 20% fats, 40% proteins and one can see the calories for each macronutrient is Table 2 (second row).

Table 2. Suggested diet content.

Type	Carbohydrates (calories)	Carbohydrates (grams)	Fats (calories)	Fats (grams)	Proteins (calories)	Proteins (grams)
In norm	212.5	53.125	127.5	14.17	85.0	21.25
Out of norm	170.0	42.5	85.0	9.45	170.0	42.5

The main output of our system for diet recommendation is focused on the generation of alternative menu suggestion with a particularly fitted diet, in terms of solving a constraint satisfaction problem. The interface of the system is still in command line and the full completeness of a GUI is part of our future work of improving the functionalities of the system.

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6 Conclusion

The paper discusses some results concerning an original ontology-based decision support system for dietary recommendations for T2DM. The created DSS is based on the development and use of an appropriate extension of DMTO with a set of production rules, for precise personalized dietary recommendations relevant to T2DM treatment. The workflow of our DSS is based on the successful integration of a number of modern semantic technologies and provides real semantic interoperability of the system with other healthcare information systems. An appropriate user interface that will provide personalized visualization of the generated results, oriented to the requests of end users with different profiles, is under development. We intend to develop an application interface module that will read the patient data from their EHRs in compliance with all requirements for personal data protection.

Acknowledgments

This research is supported by the National Scientific Program "eHealth". Logistical support was received from the National Scientific Program "Information and Communication Technologies for a Single Digital Market in Science, Education and Security (ICTinSES)".

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