An Ontology-Based Medical Information Management System for Electronic Claim Processing Systems

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Research article

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Abstract

Background The electronic claim processing (ECP) systems in healthcare insurance require, naturally, comprehensive, and secure management of medical information. Even though the state of the art ECP systems can read the payment rules written in plain-text, there are hundreds of rules (each including tens of conditions) in a conventional ECP system. The conditions of the rules, in turn, refer to thousands of medical entities and concepts. Although domain experts can manage the plain-text payment rules, the length and complexity of the rules yield a lack of understandability and an increase in-rule and inter-rule inconsistencies. Hence, a more efficient and straightforward system is required. This study aims to make the medical data bank that is used for the claim management system more efficient by using ontology.

Method We proposed ontology- based on the medical information management system (ONTMIMS) in healthcare insurance- to simplify the payment rules. 1,312 sets of diagnosis and health services are included in ONTMIMS. The development of the ontology comprises four stages: i) specification and conceptualization; ii) formalization; iii) implementation; and, iv) evaluation. Protégé and Apache Jena library are conducted as tools, and the ONTMIMS is used in a real-life ECP system.

Results The experiments indicated that ONTMIMS increased the understandability from 35.1% to 64.9%. Distinguishing in-rule inconsistencies increased from 65% to 82.5%, and distinguishing inter-rule inconsistencies increased from 78.8% to 85%.

Conclusions Ontology, as in many other studies, is very useful in representing and processing information. That is the first study using ontology in ECP systems used in health insurance institutions. The results showed that ontology increased the in-rule and inter-rule consistency and made the rule sentences more understandable by the domain experts.

Background

Due to the comprehensive medical knowledge necessity, the health insurance companies (HICs) generally have an independent unit for health insurance studies. The variety of the policies of insurers and the contracts signed with health care providers (HCP) generate extremely detailed healthcare insurance processes and payment rules that are very difficult to manage.

The electronic claim processing (ECP) systems, as the core component of health insurance information systems, carry out the claim processing procedures by integrating relevant information systems, such as the Policy Management System, HCP Contract Management System, and Damage Management System, as depicted in Fig. 1. In addition to the relevant legislation and laws, ECP systems are responsible for processing the claims concerning the two primary reference documents: the policy of the insured and the contract signed between the HIC and HCP, as shown in Fig. 2 [1].

The ECP Systems and Its Components

The ECP systems have several components, including rule repository, rule engine, medical information data bank, etc. A typical ECP system with relevant components is depicted in Fig. 3.

Generally, when a claim arrives at the ECP system, the rule engine needs to decide whether the claim is approvable or not by processing the payment rules in the ruleset (Please refer to the patent document of “healthcare claims navigator” [2] to get a more comprehensive and detailed explanation of a conventional ECP).

The rules have at least one condition phrase and a single rule action (APPROVE or DECLINE), which is triggered automatically when any of the conditions are not satisfied. Since the number of covered healthcare services and conditions more than the uncovered ones, most of the rule engines prefer using DECLINE as the rule action to decrease the number of rules and keep the structure as simple as possible.

However, sometimes, the decision cannot be taken by the ECP system itself, and the claim needs to be evaluated by a domain expert. Hence, even after choosing the DECLINE approach, it must be forked into two actions: DECLINE and REFER TO AN EXPERT.

Since there are hundreds of payment rules in a conventional ECP system, the management of the payment rules raises another challenging problem, “the rule management.” In an ordinary payment rule, there may be tens of different conditions about the diagnosis, symptoms, branches, services, etc. which are connected by operators, such as AND, OR, etc. Notice that, in most information systems, the rules are written by the software developers, and those rules are readable and understandable by only software developers. This obstacle is vital for domain experts who are primarily responsible for managing the rule management process. In order to overcome this obstacle, in some applications, the payment rules are defined as Access Control Lists (ACLs) [3], [4]. In this approach, the criteria of the actions (DECLINE and REFER TO AN EXPERT) are listed as lines, and the rule engine checks if the claim passes all those criteria one by one. If any of the criteria cannot be satisfied, the rule action is taken. The ACL approach is widespread and beneficial in different domains, such as network proxy servers [5] and file systems [6], [7], and database systems [8]. Although they are very successful on a per-object basis, they have disadvantages when managing per-subject basis authorization [4]. Consequently, they are not suitable for managing a complex and large number of payment rules within the health insurance domain.

Another alternative is to write the payment rules as plain text, which can then be read by the domain experts and to interfere with the rule management process. One of the most enhanced solutions for this is the Oracle Policy Automation™ (OPA) [9] application. Another solution is Claimer ECP™ [10]. Claimer ECP has a rule engine that is capable of interpreting the rules written as plain text by the domain experts by merely considering some writing rules.

Although writing the payment rules as plain text is an essential advantage, there are still three critical challenges that these payment rules pose, as follows.

1. Understandability: The rules may be too long and complicated to understand and interpret by the domain experts.
2. Consistency: The healthcare services may be included in more than one set which is used in the same rule in different conditions. If one condition yields approving, while the other one is declining the payment request

in the same rule, and the claimed healthcare service is the member of more than one set used in the conditions, then the payment rule yields an in-rule inconsistency problem.

3. Inter-rule Consistency: Some rules may be inconsistent with others. Such inconsistencies are especially challenging to detect when there are many rules, and more than one domain experts are managing the rules.

Rule Types ECP Systems in Healthcare

There are different rule types in the health insurance domain. The rule may be a “common medical rule,” which is based on well-known medical rules and/or procedures, i.e., checking the services which can only be given to male or female, etc. The general conditions rule is the country-based rules defined by the regulatory authority of the country. For example, the post effects and damages of a suicide or crime attempts are generally expressed out of the coverage of the policies. The special condition rules are valid for only institutional policies and set some conditions, like pregnancy, out of the coverage. On the other hand, the exclusion rules are considered only for individual policies and exclude the risky conditions which are related to the previous health status or the risky conditions of the person. Finally, the common insurance rules are the remaining rules used by HICs to manage the claim process more precisely. Such rules are mostly defined to detect suspicious cases or to evaluate some claims by the experts instead of processing them automatically via ECP.

The Structure of the Payment Rules

The basic structure of the payment rules of Claimer ECP used in this study is represented in Table 1.

Table 1
The basic structure of the rules used in this study

AB	C	D	E	F	G	H [A◇G]	I	J	
If	• ALL • NOT_ALL • AT LEAST ONE • EXACTLY ONE • ...	of the	• AGE • GENDER • DIAGNOSIS • SERVICE • MATERIAL • INPATIENT/ • OUTPATIENT • INPATIENT DURATION • BRANCH • START DATE OF POLICY • END DATE OF POLICY • BENEFIT • DATE OF LAST EXAMINATION • ...	is	• IN • NOT IN • EQUAL TO • NOT EQUAL TO • BETWEEN • NOT BETWEEN • MORE THAN • LESS THAN • ...	• NUMBER • DATE • A SET OF [DIAGNOSIS], [SERVICE] [BRANCHES] [MATERIALS} [DRUGS]	• AND • OR • NOR • XOR	then	• DECLINE • REFER TO AN EXPERT

The phrases in the columns from A to G in Table 1, are used to construct a single condition of the payment rule. Column H is used to join two conditions when it is needed to add a new condition. When it is not necessary to add a new condition, the Column I and J are enacted to trigger the action of the whole payment rule sentence.

Notice that Column D contains many parameters, which can be an attribute of the patient, claim, branch, policy, HCP, etc. The columns from B to D construct an operand to be used in the condition of the payment rule. Column G contains the second operand of the payment rule sentence, which can be a number, date, or a set of diagnoses, health services, drugs, materials, branches, etc. Constructing the sets of diagnoses, services, materials, drugs, etc. requires a comprehensive medical information management study. For example, a set of

diagnoses of, let us say, Diabetes Mellitus, will contain all relevant diagnosis codes from a standard diagnosis list, such as International Statistical Classification of Diseases and Related Health Problems 10 (ICD10) [11]. Similarly, the set of health services of Diabetes Mellitus will include all services possibly given to patients with diabetes, which requires continuous management.

Finally, Column F contains the condition function, which checks whether the first operand (the combination of columns B, C, and D) is satisfied with the second operand (Column G). The action (of Column J) is processed by the ECP system if and only if the claim satisfies all the requisite conditions.

Regarding the above description, a rule sentence may be structured by selecting the relevant phrases from the following columns orderly, as follows:

A payment rule sample: (A, B, C, D, E, F, G), H, (A, B, C, D, E, F, G), H, (A, B, C, D, E, F, G), H, ..., I, J.

The Difficulties in Medical Information Management

Because of the diversity in policy types, there are generally hundreds of payment rules to be processed by the ECP systems. Moreover, the payment rules will include any of the sets of items given in Column G of Table 1 as a parameter, which means all such sets of items must be prepared by the domain experts beforehand. The most common way of preparing those sets is grouping the items (diagnosis, services, branches, laboratory exams, reimbursements, etc.). For example, the following rule requires preparing a set of a diagnosis named as “Diabetes Mellitus” from the standard diagnosis codes, i.e., ICD 10:

If the DIAGNOSIS is in “THE SET OF DIABETES MELLITUS DIAGNOSIS” and if ... then DECLINE!

Related Works

Ontologies have been widely used in healthcare, especially in facilitating a common vocabulary. The Systematized Nomenclature of Medicine-Clinical Term (SNOMED-CT) [12] and RadLex [13] are outstanding examples. Ontology has been used in healthcare providers for different purposes, such as evidence-based medicine [14], modeling the anatomy [15], developing clinical decision support systems [16], semantic description of computer tomography (CT) images [17], modeling the gene [18], national health data dictionaries [19], creating terminologies [20], [21], knowledge engineering [22], [23], biomedical informatics [15], [24], [25], language engineering [26]–[28], and information systems [29]–[31]. Since these ontologies enable us to represent the concepts with their relations, it also has a usage area within information management [32], [33], etc. On the other hand, there are only a few studies using ontology in healthcare insurance. One of them [34] is just proposing the use of semantic Web techniques to minimize the information asymmetry between clients and providers in Indian healthcare insurance domain. Another one is a patent [35] proposing an information system, including an ontology to convert non-standardized billing codes to standard ones. But, no studies using ontology in the medical databanks to be used in claim processing have been found in the literature.

Method

This paper aims to propose an ontology-based medical information management system, i.e. *ONTology-based Medical Information Management System (ONTMIMS)*, for ECP systems, whereby ontological concepts and relations support the payment rules, so that the domain experts will enable to write more straightforward payment rule sentences so that they can be

sure that these rules become more understandable and satisfy both in-rule and inter-rule consistencies.

The Method of Ontology Development

Although there is no standard method for ontology development, which is called “ontology engineering,” there are still some frameworks [36] which can be regarded as an advisory for this study. One of those ontology development methods is proposed by Nicola et al. [37], which starts with the creation of the domain “map,” in this case include the diagnosis, services, etc., and the hierarchy between those concepts. Subsequently, other concepts that are related to the beginning concept set are obtained. Finally, the relations between the concepts are set, and by iteration, the concepts and relations are redefined.

A healthcare domain-specific alternative of the ontology development method is proposed by Kuziemytsky and Lau as a four-stage approach, as follows: i) specification and conceptualization, ii) formalization, iii) implementation and iv) evaluation and maintenance [38]. Because of its step by step approach, the author found the model of Kuziemytsky and Lau easier to implement, and thus, the author preferred to use it in this study and proceed as described in the following sections.

Specification and Conceptualization

To validate the concepts and their specifications, the researcher firstly collected the sets of items used for representing the groups of diagnosis, and health services in the payment rules of Claimer ECP, as indicated in Table 1, Column G. In this regard, 1,312 diagnosis and health service sets are obtained. Regarding the data analysis, the author followed the research method called Grounded Theory (GT) [39], [40]. GT has three coding approaches, such as open, axial, and comparison [40]. Since there are the sets that are already representing the groups of diagnosis and health services, the researcher preferred the open approach. In this regard, existing sets of diagnoses and health services are analyzed, and it is recognized that there are some attributes, as presented in Table 2, which describe the sets and can help to determine the final concepts.

Table 2. Attributes and values of the item sets, i.e., diagnosis, services, etc.

Attributes	Values
Type of the list	{exclusion, rule, special condition}
Scope	{pregnancy, specific diagnosis, service, diagnosis group}
Allergic	{yes, no}
Congenital	{yes, no}
Chronic	{yes, no}
Surgery	{yes, no}
Trauma	{yes, no}

Formalization

In order to describe the entities and their relationships in the ONTMIMS, Description Logics (DL) [41] is incorporated. There are three types of entities in the model, such as concepts, roles, and individual names. Concepts are the sets of individuals. The individuals, in this study are not items such as diagnosis, health services, etc., but the sets of items, i.e., a set of diagnosis, a set of services, etc. as given in Table 1, Column G. The roles are the relationships between individuals, which are represented by unique individual names from the relevant standard registries, such as ICD 10 [11], and national health interventions of Turkey [42], [43], etc.

Considering the analysis of the existing 1,312 sets of items involved in the payment rules at the data collection stage, the author first recognized that there are some essential medical concepts, such as organ, system, and pathology, which will most probably be related with all possible domain concepts and are also capable of being used in payment rules as parameters. Thus, the author decided on such concepts with their instances, as indicated in Table 3.

Table 3. Medical concepts in ONTMIMS

Concept	Relation with Domain Concepts	# of Instances
Organ	:OccurredInThisOrgan	92
System	:OccurredInThisSystem	14
Pathology	:ResultsOfThisPathology	49

In addition to the medical concepts, the researcher extracted some domain concepts that are mostly related to the 1.312 sets of items, i.e., individuals of DL, as listed in Table 4.

Table 4. Domain concepts in ONTMIMS

Concept	Description
Anemia	The set of items from the individuals of diagnosis and health services that are related to the anemia occurred as a result of blood production defect and hemorrhage pathology and related to the hemopoietic or circulation or digestive systems.
Diabetes	The individuals of diagnosis and health services which are chronic and related to the endocrine system and occurred as a result of hyperglycemia pathology.
Pregnancy and Delivery	The individuals of diagnosis and health services which are related to pregnancy and delivery.
Stroke	The individuals of diagnosis and health services which occur as a result of stroke pathology.
Cardiovascular Diseases	The individuals of diagnosis and health services which are chronic and related to cardiovascular diseases.
Neuropathy	The individuals of diagnosis and health services which occur as a result of neuropathy pathology.
Spine Hernia	A specific subsection of neuropathy individuals which has spine hernia pathology.
Tuberculosis	The individuals of diagnosis and health services which occur as a result of tuberculosis pathology.
Tumors	The individuals of diagnosis and health services which occur as a result of any tumors.

Both medical and domain concepts used in the relations among 1,312 individuals are used in order to make the payment rules simpler. As an example, a basic description of the Diabetes Mellitus concept is given in Figure 4.

Implementation

Since there are medical and domain experts in the HIC who make the design and implementation studies, it is preferred to follow a rapid system development approach [44] for developing the ONTMIMS framework. Protégé [45] is conducted as the tool for defining domain ontology, generating a knowledge-acquisition, and defining the mappings [46]. In order to query the ontology, the Apache Jena [47] library is incorporated to create an environment where semantic web technologies can be used in Claimer ECP.

Since the ONTMIMS brings an ontology layer between the payment rule repository and existing medical information data bank in the ECP system, the architecture of the ECP system given in Figure 3 has changed, as shown in Figure 5. In the new structure, the rule engine queries the ontology directly by using the Jena library, instead of referring to 1,312 sets of items in the medical information data bank.

ONTMIMS also enables the domain experts to write new payment rules, which consist of concepts, instead of using the sets of diagnosis, services, materials, etc. Naturally, this new layer changes some parameters depicted in Table 1, as is shown in Table 5.

Table 5. The proposed rule structure by adding the ontology concepts

A	B	C	D	E	F	G	H [A à G]	I	J
If	· ANY	of the	· CASE	is	· RELATED WITH [A RELATION PHRASE]	· CONCEPTS	· AND · OR · NOR · XOR	then	· DECLINE · REFER TO AN EXPERT

A simple example is given below of a payment rule, which is checking whether the claim is related to diabetes or not.

The previous rule sample:

If AT LEAST ONE of the DIAGNOSIS is IN THE DIABETES_DIAGNOSIS_LIST OR

If AT LEAST ONE of the SERVICES is IN THE DIABETES_SERVICE_LIST OR

If AT LEAST ONE of the MATERIALS is IN THE DIABETES_MATERIAL_LIST OR

If AT LEAST ONE of the BRANCHES is IN THE DIABETES_BRANCH_LIST

...

then REFER TO AN EXPERT!

As readily seen from this trivial example, to set a rule which is related to diabetes, there should be many conditions regarding diagnosis, services, materials, and branches. On the other hand, the new rule generated by ONTMIMS would be as below:

If the CASE is RELATED WITH DIABETES, then REFER TO AN EXPERT!

Experiments

Although many studies are measuring the semantic accuracy and quality of the ontologies [48]–[50], the focus of this study is to compare the ONTMIMS with the previous system in terms of understandability, in-rule and inter-rule consistency of the payment rules from the point of domain experts' view. Thus, the experiments are conducted in three stages: i) comparing the existing payment rules with their equivalence rules using ontology in term of understandability; ii) finding in-rule inconsistencies of a set of payment rules in both previous and ONTMIMS approach; iii) finding inter-rule inconsistencies of a set of payment rules in both the previous and ONTMIMS approaches. To prevent the domain experts from any bias, they are selected from outside of the insurance company so that they cannot realize which payment rule is written relative to which approach. They are all graduate students from the healthcare management department of Istanbul Medipol University, and all have enough knowledge about the healthcare insurance system, medical data banks, ontology, and medical informatics to undertake the task successfully.

Understandability

At this stage, the pair-wise comparison method [51], [52] of analytic hierarchical processing is conducted to determine the rank of understandability. Briefly, in this methodology, the domain experts are requested to complete a comparison matrix and specify which payment rule is more understandable concerning others. The domain experts make their decisions alone, without interference by others. Since the time taken to read and understand the sentences is necessary, the domain experts are given time in correspondence to the length of the sentences, i.e., short times for a short sentence. Since there are four domain experts, the average rank is calculated for each rule.

The domain experts are given 40 payment rules so that 20 of them written by using the previous approach, and those remaining, are written via the ONTMIMS approach with precisely the same purpose and meaning. There are include 5 rules from each rule type given in section 2.2, except General Medical Rules, which are very specific to clinical cases and require clinical expertise during the experiments.

Later, the rank of each rule is calculated, and the normalized rank values are assigned as the weights of the understandability of the payment rules.

In-rule Consistency

At this stage, the same 40 rules are modified so that to create an inconsistency among the rule conditions. For example, two conditions of the rule conflict with each other; or, the rule may be in tautology or contradiction cases. The experts are requested to evaluate the rules as to whether they are consistent or not. They are warned that the consistency check should be only made by considering the subject rule only.

Inter-rule Consistency

Like the previous stage, during this stage, 20 payment rules are generated by using both previous and ONTMIMS approaches used by the domain experts, so that in total, 40 payment rules are conducted. For each approach, half of the rules are changed to create an inconsistency with other rules in the same 20 rulesets. Unlike the previous stage, the domain experts are requested to evaluate each rule, whether it has an inconsistency with other rules in the ruleset. This evaluation is repeated for each rule in the rule sets of both previous and ONTMIMS approaches.

Results

The average normalized ranks of understandability of the rules calculated at the end of the experiments are given in Table 6 (Note that the rules cannot be given explicitly due to the commercial concerns).

Table 6. Ranks of understandability of the payment rules

The Payment Rule Alias	Rank	The Payment Rule Alias	Rank
ONTMIMS Rule 1	54%	Conventional Rule 1	49%
ONTMIMS Rule 2	70%	Conventional Rule 2	38%
ONTMIMS Rule 3	58%	Conventional Rule 3	54%
ONTMIMS Rule 4	76%	Conventional Rule 4	39%
ONTMIMS Rule 5	66%	Conventional Rule 5	34%
ONTMIMS Rule 6	69%	Conventional Rule 6	25%
ONTMIMS Rule 7	54%	Conventional Rule 7	9%
ONTMIMS Rule 8	58%	Conventional Rule 8	24%
ONTMIMS Rule 9	56%	Conventional Rule 9	38%
ONTMIMS Rule 10	46%	Conventional Rule 10	23%
ONTMIMS Rule 11	55%	Conventional Rule 11	31%
ONTMIMS Rule 12	75%	Conventional Rule 12	24%
ONTMIMS Rule 13	44%	Conventional Rule 13	43%
ONTMIMS Rule 14	90%	Conventional Rule 14	35%
ONTMIMS Rule 15	74%	Conventional Rule 15	19%
ONTMIMS Rule 16	78%	Conventional Rule 16	39%
ONTMIMS Rule 17	54%	Conventional Rule 17	66%
ONTMIMS Rule 18	80%	Conventional Rule 18	33%
ONTMIMS Rule 19	56%	Conventional Rule 19	41%
ONTMIMS Rule 20	88%	Conventional Rule 20	41%
Average of ONTMIMS	65.1%	Average of Conventional Rules	35.3%

Regarding Table 6, the average normalized rank of ONTMIMS rules is 65.1%, while the conventional rules' is 35.3%. This result shows that the ONTMIMS increased the understandability of the rules by the domain experts.

The average number of true-positive (TP), true-negative (TN), false-positive (FP), and false-negative (FN) decisions of four domain experts and the consequent accuracy of the experiment are given in Table 7 below.

Table 7. Accuracy table of finding in-rule inconsistencies of the rules

Approach	Actual	Prediction		Accuracy
		Positive	Negative	
Previous Approach	Positive	9	4	65%
	Negative	3	4	
ONTMIMS Approach	Positive	10.25	1.75	82.5%
	Negative	1.75	6.25	

Regarding the experiment results, it can be easily surmised that the inconsistencies within the rules can be more easily distinguished by the domain experts when using ONTMIMS.

The average number of TP, TN, FP, and FN decisions of four domain experts and the consequent accuracy of the experiment are given in Table 8 below.

Table 8. Accuracy table of finding inter-rule inconsistencies of the rules

Approach	Actual	Prediction		Accuracy
		Positive	Negative	
Previous Approach	Positive	7.5	1.75	78.8%
	Negative	2.5	8.25	
ONTMIMS Approach	Positive	7.5	1.25	85%
	Negative	1.75	9.5	

The result of the experiment shows us that ONTMIMS enables slightly better results than the conventional approach.

Discussion

In this study, the researcher has first developed an ontology (ONTMIMS) covers the concepts referenced in the human-readable payment rules processed by ECP systems. The primary motivation of the usage of ontology was to simplify the payment rules by using ontology concepts rather than the traditional set of medical lists to increase the understandability, in-rule consistency, and inter-rule consistency of the rules.

The experiments are conducted with domain experts to demonstrate the differences between the previous approach and ONTMIMS. By using the pair-wise comparison method, the domain experts are requested to rank the understandability of the payment rules and then find the in-rule and inter-rule inconsistencies. The experiments showed that ONTMIMS increased understandability from 35.3–65.1%. Additionally, the consistencies of the payment rules can be distinguished at a rate of 82.5% with ONTMIMS, but only 65% using the traditional approach. Similarly, the inconsistencies between payment rules can be distinguished at a rate of 85% with ONTMIMS, while at 78.8% with the traditional approach. Since using ontology in an ECP system may tend to lose granularity and nuance, the domain experts should consider using it to simplify very complicated rules mostly.

Limitations

As a beginning, 1,312 diagnosis and healthcare services are included in this ontology. This scope is closely related to the payment rules used in the ECP system conducted in this study. Because of the commercial considerations, the ontology will not be public for some time. The researchers will focus on extending the ontology and measuring the accuracy and semantic quality of it soon.

Conclusion

ONTMIMS is the first ontology used in an ECP system in the healthcare insurance domain, and since this study showed that it enables more understandable and consistent payment rules, it is a good starting point to have a more comprehensive and extensive ontology aiming to cover more diagnosis and healthcare services.

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Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due the commercial reasons of the TPA company.

Competing interests

The author declares that he has no competing interests

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Authors' contributions

IK contributed the proposal of this R&D project to get the grant from TUBITAK, managed the R&D team of this project from the beginning to the end, and contributed to all work packages. IK was the only contributor in writing the manuscript.

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Figures

Figure 1

The components integrated with ECP Systems

Figure 2

The health insurance payment model [1]

Figure 3

The components of ECP Systems

Figure 4

Description of the Diabetes Mellitus concept

Figure 5

The components of the ECP system with ONTMIMS