

## Expert Doctor Verdis: Integrated medical expert system

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**Abstract:** Innovative medical technologies are developing day by day, as there is an important need for integrated medical expert systems (ESs) that will help to effectively manage and control diagnosis and treatment processes. These systems, with new approaches, have improved the experiences and capabilities of physicians to make the diagnosis of diseases.

In this work, an integrated medical ES called Expert Doctor Verdis (Ex-Dr Verdis) is developed, which combines an advanced medical information system containing various medical services supported by information technologies, with ES capabilities in a single system. This system is also one kind of decision support system. Implementation of this system is applied for vertebral column diseases. Ex-Dr Verdis is a strong decision support tool with 94% sensitivity, 71% specificity, 87% positive, and 86% negative predictive values for the diagnosis of vertebral diseases. In addition to its facilities of medical information, Ex-Dr Verdis, with a sharing platform, provides physicians with the opportunity to share and discuss their own patients, cases, experiences, and expert knowledge with other colleagues. This integrated medical ES can be used in all hospital services, such as hematology, neurology, or cardiology, by adding new expert modules for other diseases.

**Key words:** Integrated system, medical information system, expert system, fuzzy rules, diagnosis vertebral diseases, medical sharing platform

### 1. Introduction

The implementations of computer technology solve many specific problems in medicine. Having been called ‘medical information systems’, these systems enable one to reach previous medical patient records from a database and help physicians to make a prognosis and diagnosis. Medical information systems can be used to educate and assist medical professionals during clinical care, reducing the need to rely on memory. Potentially, such a system helps in increasing efficiency on one hand and reducing institutional costs on the other. It facilitates monitoring the evaluating quality of medical care services. It also eliminates unnecessary data recording and provides accurate and useable data for evaluating and planning medical services.

An expert system (ES) is a kind of information system and acts as a human expert for users by using knowledge base rules in the specific area. The ES consists of the knowledge base and a software module that has an inference engine for decision support to end users in the form of advice.

To analyze large volumes of data, data mining that integrates techniques such as artificial intelligence, machine learning, statistics, database systems, and pattern recognition is used. There are a great number of data-mining algorithms for different data analysis tasks.

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Data-mining methods are also used to develop ESs. In the rule-based knowledge method, knowledge is represented in the form of condition statements, such as If-Then rules. Rule-based ESs have been developed for many different areas [1].

ESs are used successfully in the medical diagnosis field. The knowledge base of medical ESs consists of medical information, rule-extracted patient symptoms, and advice for the diagnosis of the patient's diseases. Successful implementations of the artificial neural network (NN)-fuzzy integrated approach in medicine have been reported for diagnosis, treatment, and prediction. Ceylan et al. [2] developed an automated diagnostic system using electrocardiogram (ECG) arrhythmias. In this diagnostic system, fuzzy clustering [type-2 fuzzy c-means (T2FCM)] and the NN algorithm were combined to classify the ECG arrhythmias. The T2FCM improved the performance of the NN.

An ES-based linear discriminant analysis method and adaptive neuro-fuzzy inference system was developed by Sengur for the diagnosis of heart valve diseases [3]. An adaptive neuro-fuzzy inference system, FCM or K-means algorithm, least squares method, and gradient descent method are used for diagnosis in the system.

Başçifçi and Incekara [4] developed a web-based medical decision support system for the diagnosis of coronary heart disease (CHD). They used the Boolean function minimization method in their study. This method reduced conditions from 512 (9 symptoms of CHD,  $2^9 = 512$ ) to 94.

Most of the systems that have been developed so far in the medical field are either an ES combined with the decision support system to diagnose diseases or a medical information system to monitor patients and manage medical processes.

In this study, an integrated medical ES called Expert Doctor Verdis (Ex-Dr Verdis) is developed. Medical information system and ES capabilities are integrated in a single system. This integrated system presents many facilities to physicians or patients. Among these are making a diagnosis with artificial intelligence, monitoring patients, examining patient cases, and sharing experiments and knowledge about diseases. All of these facilities are performed through the Internet. This system can be used at any point, regardless of time and place.

## 2. Background

### 2.1. Vertebral diseases and data sets

The vertebral column consists of the vertebrae group, intervertebral disks, nerve roots, muscles, and joints. There are 26 articulating bones in an adult's vertebral column. The 24 presacral vertebrae allow movement and hence render the vertebral column flexible. The last 2 are called the sacrum and coccyx. The sacrum is a triangular bone located just below the lumbar vertebrae. It consists of 4 or 5 sacral vertebrae in a child, which become fused into a single bone after the age of 26. The sacrum forms the back wall of the pelvic girdle and moves with it. The bottom of the spinal column is called the coccyx or tailbone. It consists of 3–5 bones that are fused together in an adult. Many muscles connect to the coccyx.

The vertebral column has many important tasks, such as to safeguard the spinal cord and nerve roots, support the human body, and move the axles of body by making movement possible at 3 levels: frontal, sagittal, and transversal. Dysfunctions destroy the vertebral column and the patient can suffer from backaches. Some vertebral column pathologies causing intense pain are disk hernia and spondylolisthesis. Traumas and injuries of the intervertebral structures cause these diseases [5].

Disk hernia is a common health problem characterized by back pain from a slipped disk. If the core of the intervertebral disk migrates from its place, a disk hernia appears.

Spondylolisthesis is a condition in which a vertebral bone in the lower part of the spine slips out of the proper position onto the bone below it. It can vary depending on the amount of slippage. [5].

The database used in this work was provided by the UCI Machine Learning Repository. The data set was collected during a medical residency in spine surgery. This database includes the data of 310 patients, acquired from sagittal panoramic spine radiographies, where 100 patients have a normal anatomy, 60 patients have a disk hernia, and 150 patients have spondylolisthesis. There are important linear correlations between the shape and orientation variables at the pelvic, lumbar, and cervical areas, and they are weaker at the thoracic level and between the thoracic and lumbar areas [6].

In this database, each patient is a vector that has 6 biomechanical attributes: the angle of pelvic tilt, angle of pelvic incidence, sacral slope, lordosis angle, pelvic radius, and grade of slipping (Table 1).

**Table 1.** Attributes of the vertebral column data.

Biomechanical attributes	
api	Angle of pelvic incidence (numeric)
apt	Angle of pelvic tilt (numeric)
la	Lordosis angle (numeric)
ss	Sacral slope (numeric)
pr	Pelvic radius (numeric)
ds	Degree of spondylolisthesis
Diagnosis	Disk hernia, spondylolisthesis, normal

## 2.2. Extracting fuzzy rules for ESs

An ES is a kind of software simulating knowledge and human expertise. An ES is developed to make a decision and it has a large database of rule sets for the inference engine. They help physicians in the processes of diagnosing and treatment in medicine. The system inputs are the patient's symptoms and the outputs are the probable diagnosis or recommended treatments/drugs.

In general, machine learning algorithms and knowledge bases are used to develop ESs. Clinical cases are analyzed with machine learning techniques and produce a systematic description of the clinical features that represent the clinical conditions. In this process, the knowledge is expressed as simple rules and is used for diagnosis [7].

Fuzzy rule-based classifiers are rule generation algorithms. These classifiers have some methodologies to explore knowledge from the data set. Frequently, the knowledge is shown in the form of rules. Fuzzy rules are obtained from numerical data. This process is performed in 5 steps.

**Step 1:** Input and output spaces are divided into fuzzy regions.

**Step 2:** Fuzzy rules are generated from the given data.

**Step 3:** A degree is assigned to each of the rules to resolve conflicts among the other rules.

**Step 4:** A fuzzy rule base is created with the generated rules and linguistic rules of human experts.

**Step 5:** A mapping is determined based on the combined fuzzy rule base [8].

The fuzzy rules describing the data are of the form of [7]:

**Rule:** If  $x_1$  is  $\mu_1$ , and  $x_2$  is  $\mu_2$ , and ..., and  $x_n$  is  $\mu_n$ ,

then the pattern  $(x_1, x_2, \dots, x_n)$  belongs to class  $i$ .

$\mu_1, \dots, \mu_n$ : fuzzy sets;  $x = (x_1, \dots, x_n) \in \mathbb{R}^n$ : pattern vector;  $C_1, \dots, C_m$ : class subsets.

It is possible to create a high-performance classifier from the given data. For this, determining the membership type, number of fuzzy sets, and validation procedure is important [9].

In this study, a triangular membership function is applied to the input spaces (vertebral data set). All of the biomechanical attributes are separated into 3 fuzzy sets. One of them is given as an example below (Figure 1). Fuzzy rules are created using these fuzzy sets from the training data. The best rules are determined by computing the performance values for each rule. If a rule correctly classifies a pattern, its degree of fulfillment is added to its performance value; if not, the degree of fulfillment is subtracted. Thus, rule learning [7] is performed. Later, the obtained best fuzzy rules are located in the inference engine of the Ex-Dr Verdis system. The Ex-Dr Verdis inference engine has a structure that consists of 6 input attributes, 8 fuzzy rules, and 3 classes (Figure 2).

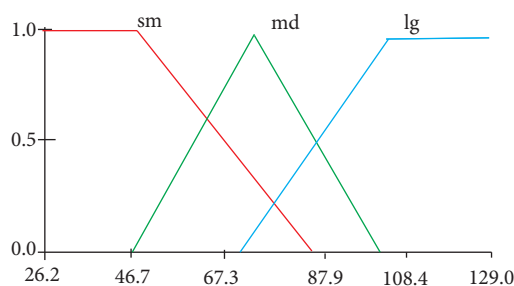


Figure 1. Fuzzy set of api attributes.

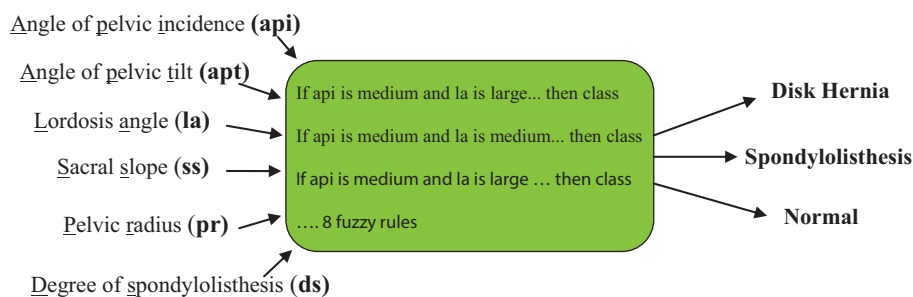


Figure 2. Inference engine of the ES.

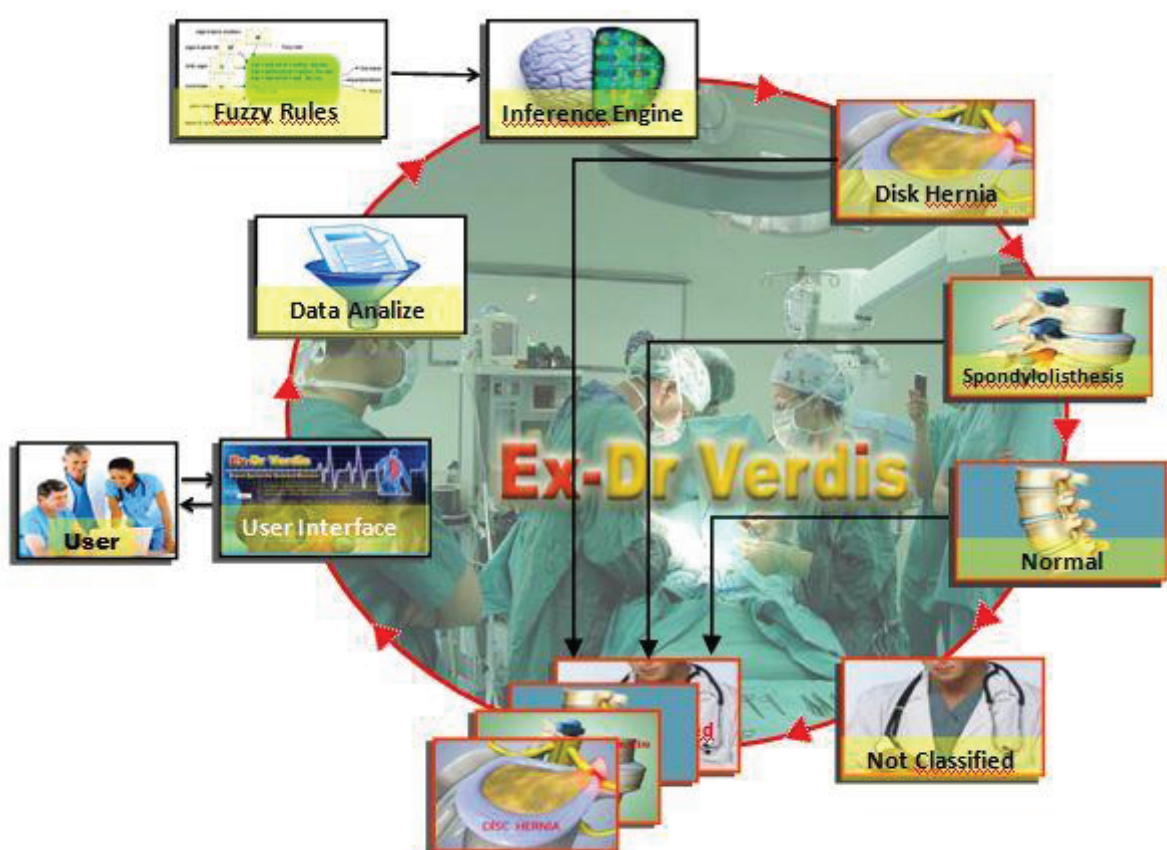
These fuzzy rules are given, respectively, below:

1. If api is small and apt is medium and la is small and ss is small and pr is small and ds is small then Disk Hernia.
2. If api is medium and la is medium and ss is small and ds is small then Spondylolisthesis.
3. If api is medium and la is medium and ss is medium then Spondylolisthesis.
4. If api is large and la is large and ss is medium then Spondylolisthesis.
5. If api is medium and la is large and ss is medium then Spondylolisthesis.
6. If api is medium and la is medium and ss is small then Spondylolisthesis.
7. If api is medium and la is large and ss is small and ds is small then Spondylolisthesis.
8. If api is medium and apt is small and la is small and ss is small and pr is medium and ds is small then Normal.

### 3. Ex-Dr Verdis system and its components

The system was designed to be user friendly for physicians, even for those who are amateur users. It was developed using the Visual Studio 2010 developer tool and SQL server 2010.

The integrated capabilities of both the medical information system and ES in a single-system Ex-Dr Verdis is designed to perform 3 main functions. The first function is individual physician operations (patient registration, follow-up, examination of cases, etc.). The second function performs diagnosis thanks to the capabilities of the ES. The third function enables the physicians to share their patients' cases and information about the vertebral diseases. The first and third functions are designed by taking advantage of the capabilities of the medical information system, and Figure 3 clearly shows the architecture of the Ex-Dr Verdis system.



**Figure 3.** Architecture of the Ex-Dr Verdis system.

Ex-Dr Verdis can analyze both recorded data, by recalling from the database, and data entered momentarily. It also verifies symptom data. If there is a problem, it gives an alert message to the user. The analyzed data move on to the inference engine where the fuzzy rules are embedded. The inference engine begins the diagnosis process. First, it checks whether the patient has a disk hernia or spondylolisthesis, respectively. If it cannot make a diagnosis for disk hernia or spondylolisthesis, then it checks whether the patient is normal or not. If the patient is not normal, then the inference engine gives the result of 'not classified'. The Ex-Dr Verdis System shows the results of the diagnosis process to the user in a related image (Figure 3).

To begin, it is necessary for the user to sign in to Ex-Dr Verdis. Users can perform processes within the limits of his/her own authority. Information about this system is placed on the entrance page. The system

consists of 5 main menu components (Figure 4). These are, respectively, Diagnose, Patient Operations, Share, Forum, and Help.



Figure 4. Entrance of the Ex-Dr Verdis system.

**Diagnose:** This component, by means of the inference engine, provides physicians with the ability to make a momentary diagnosis by entering symptoms related to a disease without registering the patient (Figure 5). Moreover, a physician can perform a batch diagnosis operation for all of the patients in the database.



Figure 5. Individual diagnosis page.

**Patient operations:** All patient registrations (record update, delete, find/save, etc.) and patient follow-up operations are performed here. The database constructed for Ex-Dr Verdis saves the detailed information of each patient. This information contains a patient number that is unique, patient photo, name and surname, symptoms, and case images of the patient. Moreover, the system allows the physician to upload the patient's case image. Thus, the physician can evaluate his/her own patient's symptoms and case image again at a later time. There is a 'diagnose' button placed on the screen. When the physician clicks on this button, Ex-Dr Verdis runs the inference engine and the result of the diagnosis is shown with an image of the disease (Figure 6).

**Figure 6.** Patient registration page.

**Share:** This component consists of 3 functions. These are, respectively, share case, Ex-Verdis Tube, and chat. All of the functions are designed so that the physicians using them can share many things about vertebral diseases and their cases.

On the 'Share Case' page, physicians can share everything about their cases, such as history, examination, pretreatment images, diagnosis, selected treatment, or postoperative images (Figures 7 and 8). Moreover, other physicians can comment on shared cases on the 'Comment' page (Figure 9).

Ex-Dr Verdis Tube is a video sharing page on which physicians can watch and upload their videos (Figure 10). The system allows physicians to add comments on the case videos. Physicians can share expert knowledge and experiences about vertebral diseases via Ex-Dr Verdis Tube with their colleagues. This facility contributes to a physician's professional development in his/her expert area.

'Chat' refers to any kind of communication through the Internet that offers a real-time direct transmission of text-based messages from a sender to a receiver. Thanks to the chat function, physicians can talk online with each other and share their thoughts about patient cases in real-time.

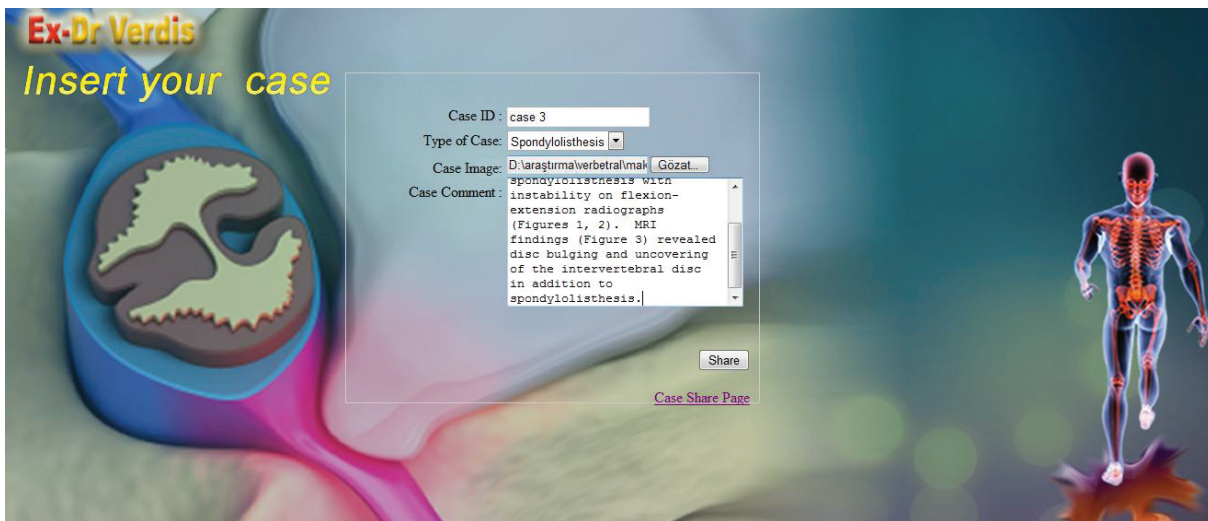


Figure 7. Insert case page.



Figure 8. Sharing case page.

**Forum:** The forum page is an online discussion message board where the conversations of physicians or patients are saved. The forum offers an opportunity for physicians to discuss vertebral diseases and cases.



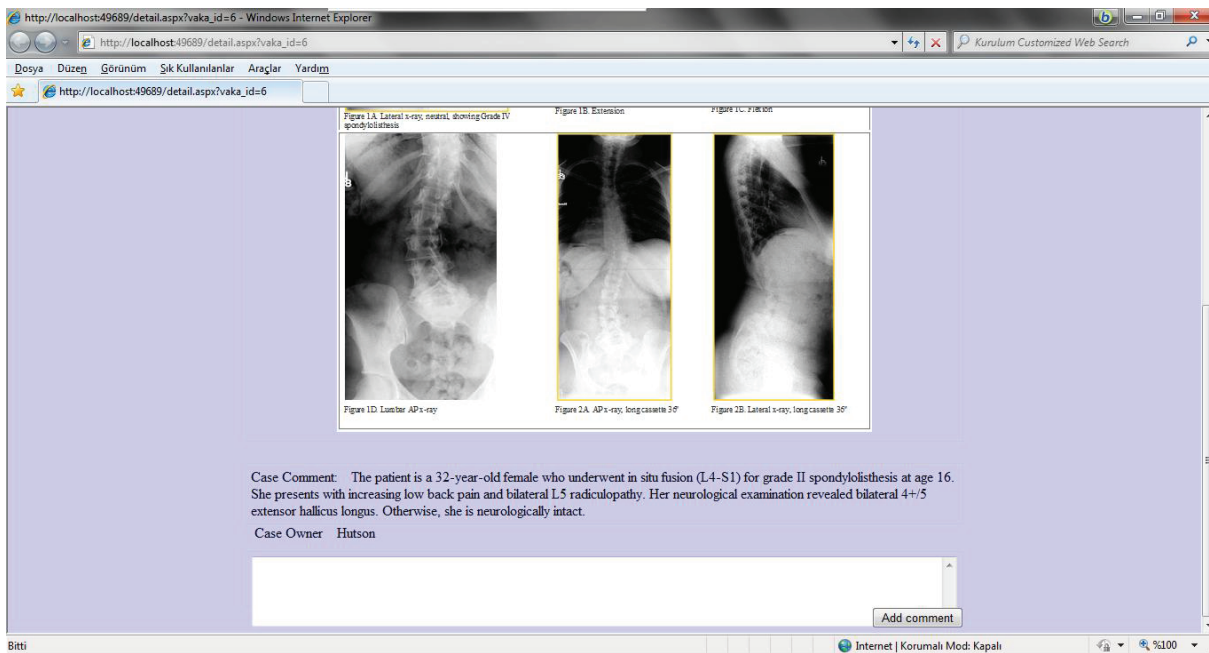


Figure 9. Detailed information about the shared case and comment-adding page.



Figure 10. Vertebral video-sharing page.

The integrated medical ES with expert module, which has a fuzzy rule base, not only helps physicians with the process of making a diagnosis but is also an important sharing platform. Thanks to this sharing platform, physicians all over the world can gather in the same area on a virtual platform. They can share and discuss their knowledge about diseases and their experiences with cases.

The Ex-Dr Verdis inference engine has a strong fuzzy rule base detecting hidden relations in cases not diagnosed by physicians. Ex-Dr Verdis can make a diagnosis with 87% positive and 86% negative predictive values for vertebral diseases. In addition, this system can be used by students training in medicine.

#### 4. Discussion and conclusion

Recent developments in artificial intelligence have led to the emergence of ESs. These computational tools are designed to capture and make available the knowledge of a particular area of expertise. Medical diagnosis

has been the most appropriate field for ES applications, because there is more fuzziness in diagnosis and it is difficult to detect the limits between health and disease.

Medical ESs are designed to support a physician's decision making by providing expert knowledge rather than routine operational information [10]. To date, many medical ESs have studied the diagnosis of disease, and these studies will continue.

There are some web-based diagnostic systems, such as ISABEL (a dynamic diagnostic checklist system). The system uses the patient's demographics and clinical features to produce a list of possible diagnoses. It is a helpful diagnostic tool in the emergency department [11].

The Ex-DBC system helps physicians in the diagnosis of breast cancer and prevents unnecessary biopsies. It decreases human errors by catching and interpreting points unrecognized by the experts [12]. Another system, ESTDD, can make a diagnosis of thyroid disease with 95.33% accuracy [13].

A vertebral data set was used by Neto and Barreto [14] for the classification of vertebral diseases. Their study reports results from a comprehensive performance comparison among standalone machine learning algorithms (support vector machines, multilayer perceptrons, and generalized regression neural networks) and their combinations in the ensembles of classifiers when applied to a medical diagnosis problem in the field of orthopedics. All of the aforementioned learning strategies, which currently constitutes the classification module of the SINPATCO platform, are evaluated according to their ability in discriminating patients as belonging to 1 of 3 categories: normal, disk hernia, and spondylolisthesis.

In medical diagnosis systems, reliability is very important. Some diagnostic tests can be used to achieve reliability. This process usually includes diagnostic tests and some descriptions. Diagnostic tests used in the health check are specificity, sensitivity, positive, and negative predictive values.

Sensitivity refers to the ability of the test to correctly identify those patients with the disease. Specificity refers to the ability of the test to correctly identify those patients without the disease [15].

$$\text{Sensitivity} = \text{True positives (TPs)} / [\text{TPs} + \text{False negatives (FNs)}]$$

$$\text{Specificity} = \text{True negatives (TNs)} / [\text{TNs} + \text{False positives (FPs)}]$$

The predictive value is a measure (%) of the correct value times, demonstrating the value as negative or positive. The positive predictive value is the rate of all of the true positive tests in a whole positive test. Correspondingly, the negative predictive value is the rate of all of the true negative tests in a whole negative test.

Table 2 shows fictitious data from an experiment to evaluate the accuracy of a certain test T for a certain set of patients with clinical suspicions. The data are the number of patients with and without vertebral diseases. Values can be calculated according to the diagnostic test in Table 2.

**Table 2.** The 2-by-2 table.

Test T (Ex-Dr Verdis diagnosis)	Disease present D+	Disease absent D-	Total
Test positive (T+)	True positives (TPs = 193)	False positives (FPs = 29)	222
Test negative (T-)	False negatives (FNs = 12)	True negatives (TNs = 71)	83
Total	205	100	305
*Five patients were not classified by Ex-Dr Verdis.			

$$\text{Sensitivity} = \text{TPs} / (\text{TPs} + \text{FNs}) = 193 / (193 + 12) = 0.94.$$

$$\text{Specificity} = \text{TNs} / (\text{TNs} + \text{FPs}) = 71 / (71 + 29) = 0.71.$$

$$\text{Positive predictive value} = \text{TPs} / (\text{TPs} + \text{FPs}) = 193 / (193 + 29) = 0.87.$$

$$\text{Negative predictive value} = \text{TNs} / (\text{TNs} + \text{FNs}) = 71 / (71 + 12) = 0.86.$$

According to diagnostic test results, the ability of Ex-Dr Verdis to correctly identify patients with the disease is very good. The high sensitivity (94%) indicates that there are few false negative results and thus fewer cases of disease are missed. A high specificity means that there are few false positive results. It may not be feasible to use a test with low specificity for screening, since many people without the disease will screen positive and potentially receive unnecessary diagnostic procedures. The specificity of the system is meaningful. It can be designated as having 71% accuracy in finding patients without the disease as negative.

Ex-Dr Verdis is very different from other systems used in medical diagnosis because this system is not only a strong diagnostic tool in which the AI technique is used, but it is also a system that has the capabilities of an advanced medical information system. The system was developed with a completely user-friendly interface and allows physicians to share many things with their colleagues, such as experiments, medical knowledge, and the images and videos of their own patients. Moreover, since the Ex-Dr Verdis system is web-based, it is accessible regardless of time and place. The system can be used in every hospital service by adding new expert modules for other diseases.

Physicians try to follow new developments in their field and it is very difficult for them to spare sufficient time for their patients. As they have limited time to make decisions in many medical cases, physicians have to make rapid judgments, depending on the physician's sufficient memory. A review of the literature or other investigations can rarely help the physician make an accurate decision for a particular case when relying on the latest knowledge for such cases. Ongoing training and recertification activities for physicians provide them with more information; however, the human mind is limited and can recall only certain knowledge, most of which cannot be known by many other individuals [16]. Moreover, all physicians do not have the same grade of expert knowledge and experience about diseases.

Overcoming these disadvantages is possible with integrated medical ESs, developed to help physicians in making decisions such as appropriate diagnostic, prognostic, and therapeutic decisions and to help organize, store, and retrieve appropriate medical knowledge needed by physicians and practitioners during medical operations. However, it is seen that they are reluctant to use the systems. If they support the studies by using the systems, more advanced tools in medicine will be developed in the near future.

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