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Review article

Computer-Based Medical Decision Support System based on guidelines, clinical pathways and decision nodes

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A continuous and dynamic development of medical sciences which is currently taking place all over the world is associated with a considerable increase in the number of scientific reports and papers of importance in enhancing the effectiveness of treatment and quality of medical care. However, it is difficult, or, indeed, impossible, for physicians to regularly follow all recent innovations in medical knowledge and to apply the latest research findings to their daily clinical practice.

More and more studies conducted both in Poland and worldwide as well as experience from clinical practice in various countries provide convincing evidence that various systems supporting medical decision-making by physicians or other medical professionals visibly improve the quality of medical care. The use of such systems is already possible and recently has been developing especially dynamically, as the level of knowledge and information and communication technology now permits their effective implementation.

Currently, electronic knowledge bases, together with inference procedures, form intelligent medical information systems, which offer many possibilities for the support of medical decision-making, mainly in regard to interactive diagnostic work-up, but also the selection of the most suitable treatment plan (clinical pathway). Regardless of their scale and area of application, these systems are referred to as Computer-Based Medical Decision Support Systems (CBMDSS).

Key words: *clinical pathways, decision nodes, Electronic Health Records, guidelines, informatisation of health care system, musculoskeletal rehabilitation*

1. Introduction

Current diagnostic work-up and rehabilitation of musculoskeletal system are based on state-of-the-art measuring and diagnostic equipment, the use of suitable physiotherapeutic means and methods as well as storage of functional data to aid monitoring the multistage rehabilitation. The latest technology, including IT solutions, has thus permanently entered the realm of medicine and physiotherapy [1], [2].

A continuous and dynamic development of medical sciences which is currently taking place all over the world is associated with a considerable increase in the number of scientific reports and papers of importance in enhancing the effectiveness of treatment and quality of medical care. However, it is difficult, or, indeed, impossible, for physicians to regularly follow all recent innovations in medical knowledge using traditional means (library: scientific magazines, books and even the Internet, etc.) and to apply the latest research findings to their daily clinical practice. As a result, selected treatments are frequently suboptimal and, in many cases, even harmful to the patient.

Under the current working conditions of doctors, as well as rehabilitation and physiotherapy specialists, these medical professionals only have several minutes to examine individual patients and decide how to treat them. During a patient's office visit, the doctor, or physiotherapist, not only has to do what he or she has been trained to do in diagnosing diseases and making medical decisions, but is also responsible for clerical

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work connected with the need to keep medical records in the form required for cost accounting, as well as for writing out prescriptions and referrals for additional tests, etc. During an appointment, doctors have to make their decisions based solely on their knowledge and experience. There is no time to quest for additional information in books or scientific medical databases. Doctors may only use these additional sources of knowledge after admission hours.

More and more studies conducted both in Poland and worldwide as well as experience from clinical practice in various countries provide convincing evidence that various systems supporting medical decision-making by physicians or other medical professionals visibly improve the quality of medical care. The use of such systems is already possible and recently has been developing especially dynamically, as the level of knowledge and information and communication technology now permits their effective implementation. Although information technologies were first introduced to the world medicine in the 1970s, it was only the rapid development of modern information technologies in the 1990s that allowed the development of information systems supporting broadly defined medical activity [2]–[6].

Currently, electronic knowledge bases (including Electronic Health Records (HER)), together with inference procedures, form intelligent medical information systems, which offer many possibilities for the support of medical decision-making, mainly in regard to interactive diagnostic work-up, but also the selection of the most suitable treatment plan (clinical pathway). Regardless of their scale and area of application, these systems are referred to as Computer-Based Medical Decision Support Systems (CBMDSS). Their role in the health care process is presented in figure 1 [1], [2], [7]–[9].

2. Characteristics of Computer-Based Medical Decision Support Systems

The notion of a Computer-Based Medical Decision Support System, or 'Clinical Decision Support System' as it is more commonly referred to in the English-language literature, is not precisely defined [8]–[11]. The term is usually understood to denote any computer system generating partial or comprehensive sets of information used by the medical personnel as an aid in making medical decisions. In line with the principles of evidence-based medicine, medical (clinical) decisions are to be based on the facts and findings of objective diagnostic examinations. Because of the cost of medical services and the fact that they are demanded on a mass scale, medical decisions also have to be cost-contained.

Computer-Based Medical Decision Support Systems can be divided into the following classes [7]:

– Computer-Based Health Information Management Systems,

– Computer-Based Monitoring and Alerting Systems,

– Computer-Based Diagnostic and Therapeutic Support Systems,

– Computer-Based Communication and Remote Group Work Systems,

– Computer-Based Comprehensive Clinical Support Systems.

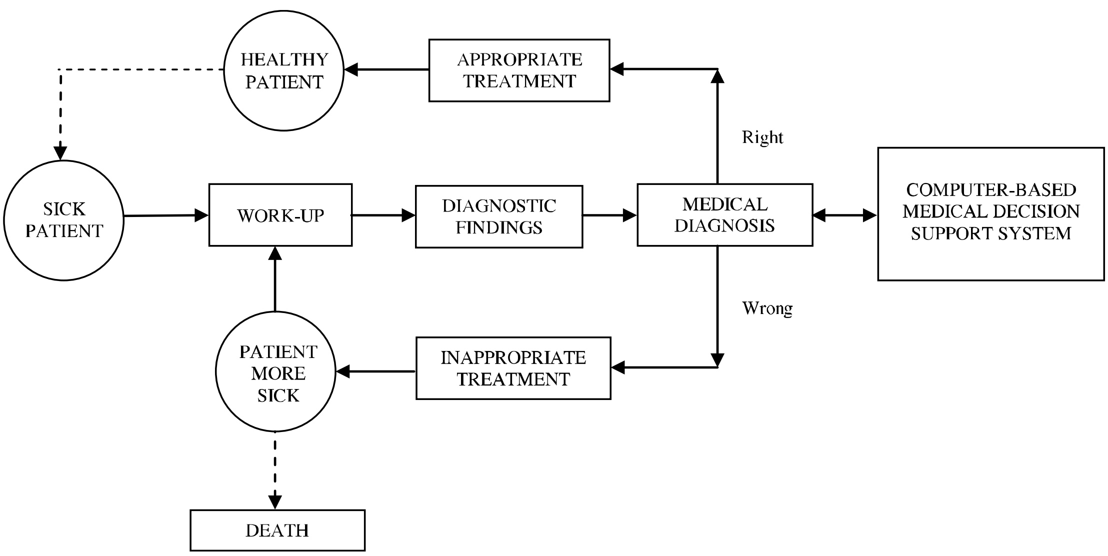

Fig. 1. Diagram of CBMDSS-based health care system

Computer-Based Diagnostic and Therapeutic Support Systems are currently being developed most intensively. Based on patients' medical data and electronic descriptions of medical conditions, they generate suggestions, or even ready-to-use proposals for diagnostic and therapeutic decisions concerning individual patients. In order to generate such hints, these systems use a wide variety of techniques and technologies. The so-called clinical pathways or guidelines are generated virtually automatically. These systems most often rely on the elements of artificial intelligence, the theories of inference, decision tables, fuzzy set and rough set-based techniques, and, most importantly, expert system technologies. This class of systems, although developed much later than passive systems of information management or monitoring and alerting systems, is currently the fastest developing class of computer-based systems. Thousands of systems of this kind, focused mainly on specific disease entities or selected classes of diseases, are in operation all over the world nowadays.

These systems can be used once a preliminary diagnostic orientation (clinical impression) has been provided and it matches a specific condition or group of diseases of the same area.

Computer-Based Comprehensive Clinical Support Systems (CBCCSS) constitute the most complete and comprehensive form of an integrated medical support system. The systems of this type are, in a way, an aggregation of the four classes of systems described above, having an advanced module of continuously updated electronic medical databases, a module of descriptions (models) of disease entities, a module for monitoring and alerting to off-reference-range parameters and, most importantly, an algorithmic module for generating ready to implement "clinical pathways" and guidelines. The entire system is embedded in a network environment via suitable interfaces, which enables full multimedia communication both within the health care unit as well as between different facilities. These systems offer credible, well-founded evidence-based hints and suggestions, which may be used by medical personnel of all levels, provided that the final decision has to be made by the medical personnel.

A modern CBCCSS, as mentioned earlier, may facilitate the implementation of many support functions, such as automatic generation of medical guidelines, comprehensive treatment plans (clinical pathways), updating EHRs, patient histories and other medical documents (e.g., Medical Services Register, statements for Regional Health Funds and the National Health Fund, etc.) [12]–[15]. CBCCSS operation is based on the use of Artificial Intelligence in Medicine (AIM) in developing software systems allowing for the generation of all kinds of information to aid diagnosis and treatment. As opposed to classic methods based on statistical research and theory of probability, AIM combines theoretical and experimental knowledge about disease entities, symptoms and examination findings expressed as medical (health) parameters, which are then fed into an "inference module" in order to support medical decision-making by personnel at all levels. Thus, CBCCSS-class Computer-Based Decision Support Systems are all based on appropriately defined models of patient's health, disease entities and treatment plans, as well as algorithms for generating medical diagnoses, guidelines and clinical pathways [7].

In the next chapter, there are presented the examples of sample elements of modelling some Computer-Based Medical Decision Support subsystems that exert the greatest impact on the IT and organisational determinants of the systems with regard to the improvement of selected medical conditions involving the knee joint.

3. Key IT terms: guidelines, clinical pathways and decision nodes

Guidelines are an increasingly popular way of disseminating clinical medical knowledge. A guideline is a methodically developed set of recommendations concerning a specific health problem which serves as a helpful tool in the decision-making process. Using them allows for rationalising the actions undertaken to make diagnosis, treatment and prevention more effective and ensures a high standard of health services. Guideline documents are also commonly used by students and university teachers for didactic purposes. They are developed in accordance with the principles of evidence-based medicine by professional organisations, leading medical centres and professionals specialising in specific health problems in a particular country [16]–[19].

The so-called *clinical pathways* (care paths) are an extension of guidelines. They are used in order to optimise services rendered by hospitals both from the medical and economic perspective. A clinical pathway is an interdisciplinary plan of medical care, which may, for example, be developed locally (for a particular hospital), based on a guideline, taking into account local needs, capabilities and other factors, e.g., characteristics of the hospital's patient population. A clinical pathway defines the essential steps during treatment and nursing care along a time line, which means that it determines the method of treatment for a given disease [20]–[22]. Clinical pathways have been used for 25 years, but it was only in the mid-1990s that the medical objectives (i.e., improving the quality of health care) came to be regarded as more important than those connected with, for example, financial settlements. However, active pathways, which involve systems automatically advising the doctor or carer about the best forms of treatment and base their recommendations on data concerning a patient's current condition, are still seldom used. Two types of clinical pathways in health care units need to be distinguished: pathways for all patients diagnosed with the same condition and pathways for individual patients, customised on the basis of patient's age, sex, co-existing medical conditions, contraindications, etc. The pathways of the latter type are also referred to as patient treatment plans. It is assumed that physicians may wander off the path (treatment plan) at any time if that serves the patient's health. For the purposes of the implementation of our project, a clinical pathway was defined as a system of related actions, represented in a specified graphic standard, e.g., BPMN, GELLO, UML, OCL, XML and others. The detailed explanation and description of those computer modelling languages are outside of the scope of this report at this stage of research, whose aim is to support doctors and middle personnel during the diagnostic work-up and planning the nature and course of treatment, which ultimately improves the quality and effectiveness of medical services.

4. Sample structure of a Computer-Based Medical Decision Support System model

Regardless of the level of integration of subject areas, the modelling layer of a Computer-Based Medical Decision Support System can be presented as in figure 2 [7].

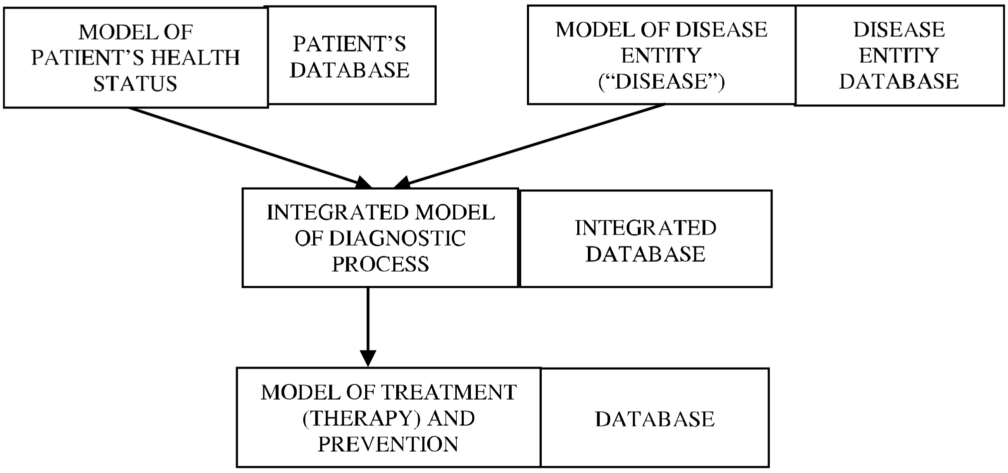

Fig. 2. Structure of a CBMDSS model

Depending on the modelling concept adopted, individual elements of the structure are represented in specific notations (modelling languages).

Computer-Based Medical (Clinical) Decision Support Systems (CBMDSS) refer to interactive computer program systems operating on a specific hardware and network platform, which support the diagnostic process and treatment methods by processing medical knowledge and the diagnostic examination findings.

Clinical pathways (CPs), as mentioned earlier, are defined as the systems of interrelated actions, represented in a particular notation and providing support for doctors and middle personnel during diagnostic work-up and determination of the nature and course of treatment, and leading to the improved quality and effectiveness of medical services. CPs may thus be represented not only in the form of computer software, but also in other forms, which is especially characteristic of CBMDSS. All clinical pathways, irrespective of their form, must include a sequence of

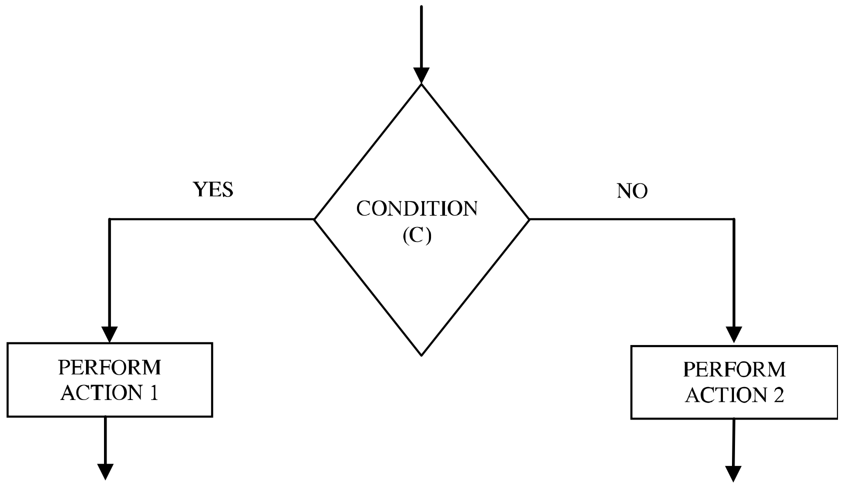

Fig. 3. A simple decision node

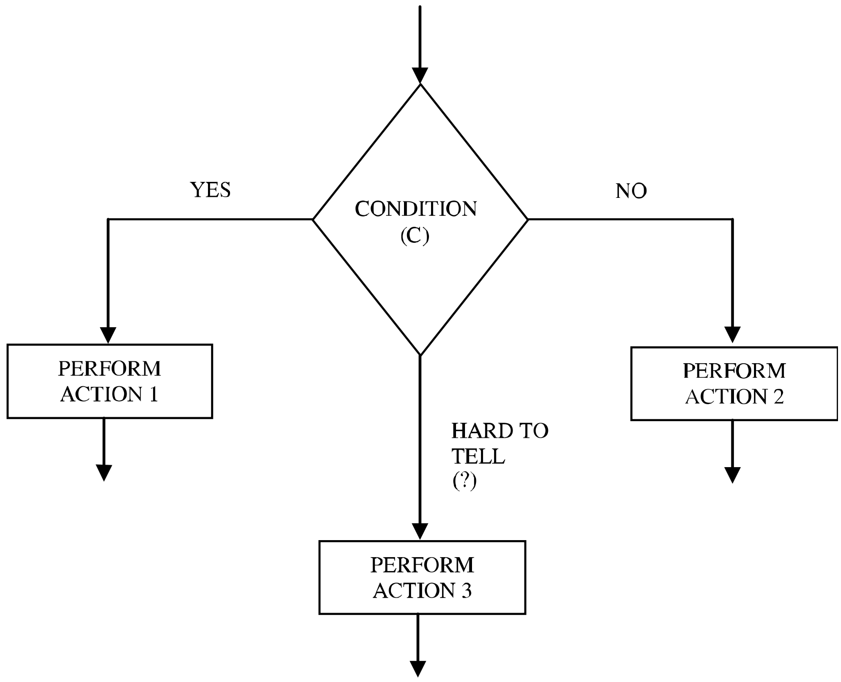

Fig. 4. A complex decision node

tasks and actions, and, importantly, also the so-called *decision nodes* (figures 3, 4), i.e., elements controlling the treatment process of individual patients suffering from the specific disease. It is these elements that generally determine the correctness and effectiveness of treatment [18].

Depending on the level of IT support, decisions in the decision nodes of clinical pathways are made either by the doctor alone (or, possibly, middle personnel), or also with the use of CBMDSS.

This paper, according to the theoretical objectives of our research project, applies to the latter situation. Thus, the overall structure (description in a specified modelling language) of a pathway depends on the selected modelling concept of medical data recording and CBMDSS inference rules [23]–[26].

In most cases, determining if the *C* condition is fulfilled boils down to finding out whether a given element $c \in C$ or $c \notin C$. The sequence of forthcoming actions, in accordance with options specified in the clinical pathway, depends on the outcome of this decision. In clinical pathways not involving CBMDSS, these decisions are made solely by the medical personnel of an appropriate level. In CBMDSS-supported clinical pathways, the decision is obviously still made by the medical personnel, but with additional clues from the system's "suggestion" (figure 4) [18], [27], [28].

5. The concept of medical decision support system modelling

Let us analyse the problem of medical decision support system modelling exemplified simply by a preliminary diagnosis in a patient following surgery for anterior cruciate ligament (ACL) injury.

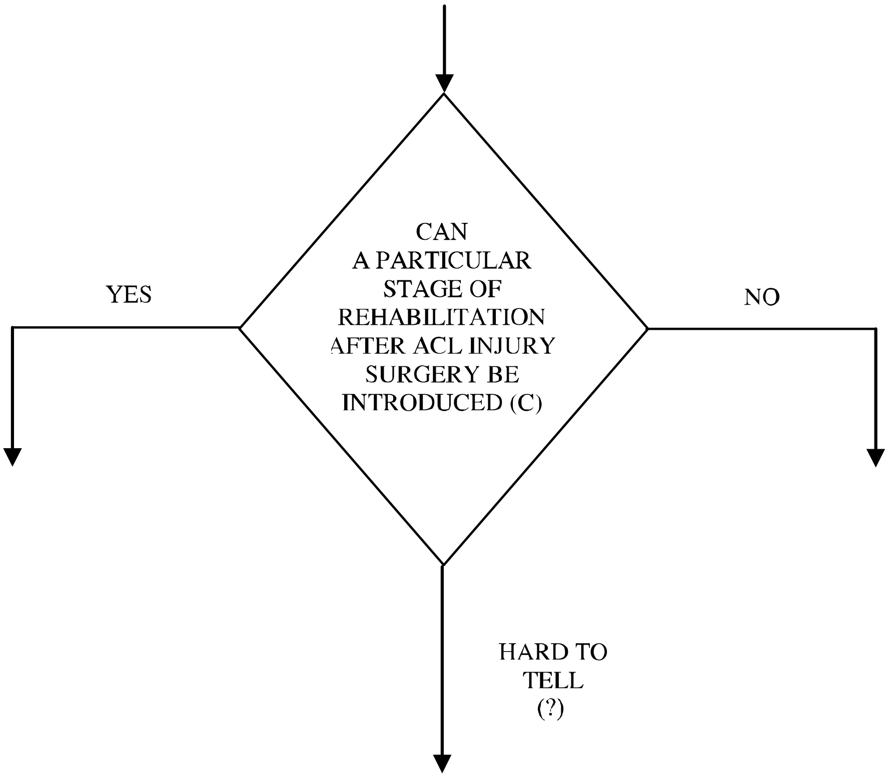

Fig. 5. Diagnostic decision node of a clinical pathway

A decision has to be made on the implementation of a particular rehabilitation scheme with the use of specific resources, methods and exercise intensity at each stage of rehabilitation [29], [30].

The condition C query diagram shown in figure 5 may be expanded in the considerably simplified way.

Figure 5, which represents a specific stage of rehabilitation after ACL injury surgery, may be clinically interpreted as follows. The outcome of the treatment is identified as positive by a specialist following a clinical examination. The patient's knee is stable and there are no complications. Thus, choosing the YES option determines a specific further course of action. If the patient's knee is unstable and complications are possible, at any stage of rehabilitation, the outcome of the treatment may be identified as clinically negative. In this case, apart from knee instability, for example, the patient's Lachman test is positive, there is >5 mm antero-posterior translation of the tibia relative to the femur, or/and at least one of the following signs or symptoms is persistently present: chronic pain, swelling, incomplete lower leg extension, significant knee joint flexion limitation, or the patient's tests positive for other knee joint injuries.

We can therefore say that (figure 6):

$$C = \{C_1, C_2, C_3, C_4, C_5\},$$

where:

C_1 = "is there any knee instability?"

C_2 = "is the Lachman test positive?"

C_3 = "is there any swelling?"

C_4 = "is there any pain?"

C_5 = "is there any limitation of knee joint movement?"

In accordance with the suggestions of specialists (experts), depending on the yes/no choices in particular decision nodes, the decision to administer particular methods, resources and exercise intensity in the course of further rehabilitation can be phrased in the way presented in figure 6.

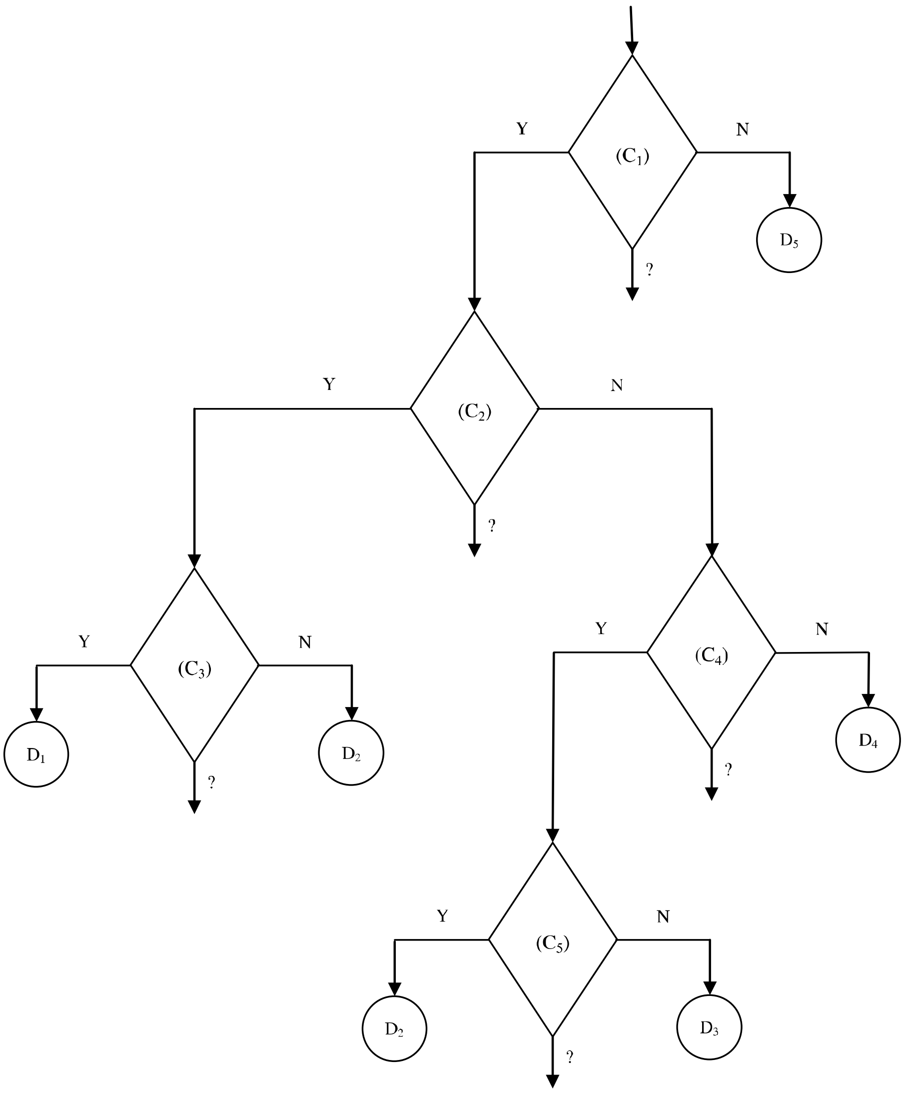

Fig. 6. Component decision nodes of the *C* node
D_1 – very high risk of commencing a given stage of rehabilitation,
D_2 – high risk, D_3 – medium risk, D_4 – low risk, D_5 – very low risk, $D = \{D_1, D_2, D_3, D_4, D_5\}$

Even a cursory analysis of the yes/no choices in component nodes (symptoms) C_1, ..., C_5 brings these questions to mind:

– what is “knee instability”?

– what is “swelling” and what does it imply?

– what does the umbrella term of “pain” exactly mean?

– what is “ limitation of knee joint movement”? etc.

The global decisions are not satisfactory, either. What does it really mean that the risk is “very high” or “medium”? How should it be measured and compared?

Also, if other factors are taken under consideration, such as other possible co-existing knee joint conditions, e.g., chondromalacia or degenerative joint disease, or the fact that the patient may suffer from more than one localized musculoskeletal problem (e.g., osteoporosis), the credibility of such a diagnosis becomes even more problematic.

As can be easily observed, the “hard to tell” option gains particular importance at all decision nodes. Each time this type of decision is made, another part of the clinical pathway would have to be activated, by, say, a request to perform an additional test. Therefore the global diagnostic decision is highly influenced by unitary “hard to tell” decisions.

On the one hand, this example, though highly simplified, shows the considerable complexity of the diagnostic process, but also the need to make tests, examinations and measurements more objective, as well as to put the diagnostic process in a wider context. Science responds to these challenges by continuous improvement of IT tools and the resultant wider array of options available to doctors.

6. Discussion

Information systems supporting medical decision-making in the administration of modern therapies, based on "guidelines" and "clinical pathways", have been developed for many years worldwide, but most of them are of the "passive" type, where the physician has to search for necessary information on his own, which is time-consuming and prolongs the diagnostic and therapeutic process.

In view of the current requirements imposed on medicine, numerous national strategies for health care development emphasise the necessity to implement "active" clinical pathways and, consequently, research on introducing such systems is under way. "Active" clinical pathways automatically provide the physician with suggestions for further therapy at every stage of the treatment based on the current state of the patient, current examination results and medical history [31]–[33]. It needs to be stressed at this point that the final decision to select a treatment at a given stage is taken solely by the physician, who may modify the standard pathway at any moment if in his/her opinion this will enhance therapeutic effectiveness and be to the advantage of the patient.

Furthermore, it is necessary to investigate ways to develop appropriate mechanisms for cooperation between the system of clinical pathways and systems containing regularly updated patient treatment histories (EHR – Electronic Health Records) [4], [34].

Therefore, in order to develop and apply a modern medical decision support system for physicians and other medical professionals, it is necessary to provide such technological, IT and organisational possibilities that *different medical specialists could extend their knowledge and store it in a manner allowing external recipients to easily understand, evaluate and use the information*, which will enable a uniform manner of *gathering, ordering and distributing medical knowledge using one or more systems* (based on the 2006 road map for development of medical decision support systems and methods at the national level in the USA) [35].

The e-Health market in various European countries is currently diversified but, according to data from the European Commission report *Evaluation of the use of information and communication technologies by practicing physicians in Europe* of April 2008 [6], [33], there is a natural tendency to extend and develop the use of e-Health in medical practice in all member states. Although the market of applications supporting medical decision systems for physicians is still poorly developed, the majority of physicians' offices are equipped with a computer and an Internet connection, which implies a vast potential for growth. It suffices to quote data from 2009, which indicate that 87% of physicians in the European Union used computers in their practice and 69% had an Internet connection (including 48% with a broadband connection) [36].

In Poland, these proportions are lower, but still 72% of physicians used computers in their practice and 62% had an Internet connection (broadband connection in the case of 32% of them) [34].

The situation presented above justifies and supports the need for finding technological, IT-based and organisational methods to enhance the effectiveness of health care, which could be achieved through the development and effective performance of numerous studies in this area of medical knowledge and practice.

One of such initiatives in Poland is the project geared towards developing a rehabilitation model for selected musculoskeletal disorders and injuries with the use of state-of-the-art methods and computer and medical equipment, carried out jointly by the College of Physiotherapy in Wrocław and Warsaw Military University of Technology [36].

These factors make standardization of health care processes a growing necessity. The first step was the introduction of algorithms and guidelines developed since the 1990s (mainly in English-speaking countries), which consisted of recommendations and suggestions for clinical practice based on measurable scientific evidence (Evidence Based Medicine, EBM) [37]–[40] and have been followed by the development of clinical pathways, or multispeciality health care plans with detailed descriptions of successive steps of treatment and nursing care along a time line [16], [17].

7. Recapitulation

In conclusion, it has to be noted that doctors, midwives, nurses, radiologists, laboratory technicians, rehabilitators have to deal with many patients, who need specific, customized health care.

In most cases, patients expect effective, top-level health care provided as fast as possible and causing them the least inconvenience. At the same time, the medical personnel have to cater for many patients in a relatively limited period of time and under high daily workload. All these factors can cause work-related fatigue, which may eventually result in a failure to find the time to keep pace with the latest trends in treating particular diseases.

Our research project is designed to offer a solution to the above described situation. By providing the right people, at the right time, with descriptions of guidelines and clinical pathways, the medical personnel can be effectively supported in providing treatment. A system of clinical pathways could constitute a *system providing hints for successive steps of treatment* for a given disease entity. In this respect, it can be treated as a support instrument for the treating personnel. It might prove especially useful for less experienced clinicians, whom this kind of a tool could help avoid making mistakes and malpractice errors. Nonetheless, it has to be stressed that no automatic system can be treated as a replacement for a doctor. This tool can only be used to support the doctor's decision making, but the final decision and its outcomes are the responsibility of an actual person. The system of clinical pathways allows for an easier access to descriptions of the treatment process, thereby increasing the quality of diagnosis and treatment. Also, if the system were equipped with a functionality allowing integration with the hospital's EHR system, it would make for a helpful tool in the much-disliked and time-consuming process of documenting the course of treatment.

With these methods and tools, experienced clinicians, heads of departments or wards will be able to define clinical pathways used at particular stages of treatment. This will allow them to establish standards of treatment in their teams/departments/wards. It is also worth remembering that our project makes it possible to create different rules at particular decision nodes within clinical pathways, the result of which will be more intellectually developed models of pathways. This makes it easier for those in charge of medical teams to continuously adapt the decision models recorded in the pathways to comply with their own knowledge and the factors that they consider most important, as well as the technological capabilities of their health care units. This, in turn, will boost the effectiveness of treatment in the unit, which is one of the most important tasks for hospital medical directors and heads of departments/wards.

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