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Artificial-Intelligence-Based Hospital-Acquired Infection Control

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Abstract

Nosocomial or hospital-acquired infections (NIs) are a frequent complication in hospitalized patients. The growing availability of computerized patient records in hospitals permits automated identification and extended monitoring for signs of NIs. A fuzzy- and knowledge-based system to identify and monitor NIs at intensive care units (ICUs) according to the European Surveillance System HELICS (NI definitions derived from the Centers of Disease Control and Prevention (CDC) criteria) was developed and put into operation at the Vienna General Hospital. This system, named Moni, for monitoring of nosocomial infections contains medical knowledge packages (MKPs) to identify and monitor various infections of the bloodstream, pneumonia, urinary tract infections, and central venous catheter-associated infections. The MKPs consist of medical logic modules (MLMs) in Arden syntax, a medical knowledge representation scheme, whose definition is part of the HL7 standards. These MLM packages together with the Arden software are well suited to be incorporated in medical information systems such as hospital information or intensive-care patient data management systems, or in web-based applications. In terms of method, Moni contains an extended data-to-symbol conversion with several layers of abstraction, until the top level defining NIs according to HELICS is reached. All included medical concepts such as “normal”, “increased”, “decreased”, or similar ones are formally modeled by fuzzy sets, and fuzzy logic is used to process the interpretations of the clinically observed and measured patient data through an inference network. The currently implemented cockpit surveillance connects 96 ICU beds with Moni and offers the hospital’s infection control department a hitherto unparalleled NI infection survey.

1. Introduction

The increasing availability of digitalized medical data of patients in a hospital permits comprehensive identification and monitoring of nosocomial infections. The now routinely used information systems in hospitals are one of the basic foundations of this procedure. The systems are capable of storing, transferring and retrieving an ever-increasing body of

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digitalized data concerning the patients' medical history, the outcome of physical examination, the different outcomes of laboratory tests, and the findings of various clinical investigations. These systems are known as hospital information systems (HISs), whose many functions include the administration of data pertaining to the admission, transfer and discharge of patients in order to render these data accessible to medical information systems (MISs) at the different wards and out-patient departments that contain the medical data of patients, as laboratory information systems (LISs) with the respectively gained laboratory findings, as well as patient data management systems (PDMSs) at ICUs with clinical, laboratory, equipment-based and nursing data.

High-quality knowledge-based support for making medical decisions based on these patient data stored in the respective information systems requires that medical knowledge be represented in a formal manner and stored in a computer system. This may be in the form of interpretations of rare or complex laboratory findings, or computer-based definitions of symptoms, diseases and treatment processes, and their inter-relationships, or rules or tabulated forms of medical decision-making procedures, to name a few.

Advances in methods of formal representation and processing of medical knowledge achieved in the fields of artificial intelligence, fuzzy set theory, and fuzzy logic permit computer-based processing of medical knowledge originally available in natural language [1]. A few examples of these are the definitions of nosocomial infections issued by CDC [2–4], HELICS [5], and KISS [6].

2. The MONI programs

At the individual clinics of the Medical University of Vienna (Vienna General Hospital), a number of algorithmic and knowledge-based identification and monitoring programs for microbiological findings and nosocomial infections have been introduced and implemented on this basis. These have been accompanied by a number of flexible statistical evaluation modules. The systems include the following:

- Moni/Germ: Germ and antibiogram monitoring for pre-defined species using specifically defined resistance patterns in newly submitted microbiological reports;
- Moni/Cross: Cross-infection monitoring by collecting information as to whether germs with resistance patterns are passed on, which—within a specific time period—have been previously registered in a different patient;
- Moni/Trend: Frequency and trend monitoring by collecting information as to whether there have been increases in the frequency of pre-defined germs beyond a "basic level" indicative of an epidemic event and how strong these deviations are; and
- Moni/Surveillance: Monitoring for nosocomial infections by collecting information as to those patients in whom the definitions of nosocomial infections represented as complex fuzzy rules are completely fulfilled, fulfilled to a certain extent, or not fulfilled at all, as indicated by the collected data in the respective information systems.

3. The Moni/Surveillance program

Figure 1 shows the methods that constitute the basis of Moni/Surveillance, a comprehensive monitoring program developed for nosocomial infections at ICUs to be surveyed by the infection control team of the hospital.

All of the Moni programs are directly connected to the LIS of the microbiology department (currently this is the electronic data processing (EDP) system of the Municipality of Vienna; later on it will be the MOLIS system of Vision4Health) as well as the PDM systems of the ICUs (here: CareVue classic of Philips). On the one hand, the Moni programs actively provide information about germs and nosocomial infections in the individual patient, give reasons, and permit rapid intervention. On the other hand, the output statistics provide information about existing germs and infections at the wards, out-patient departments, or the entire medical facility.

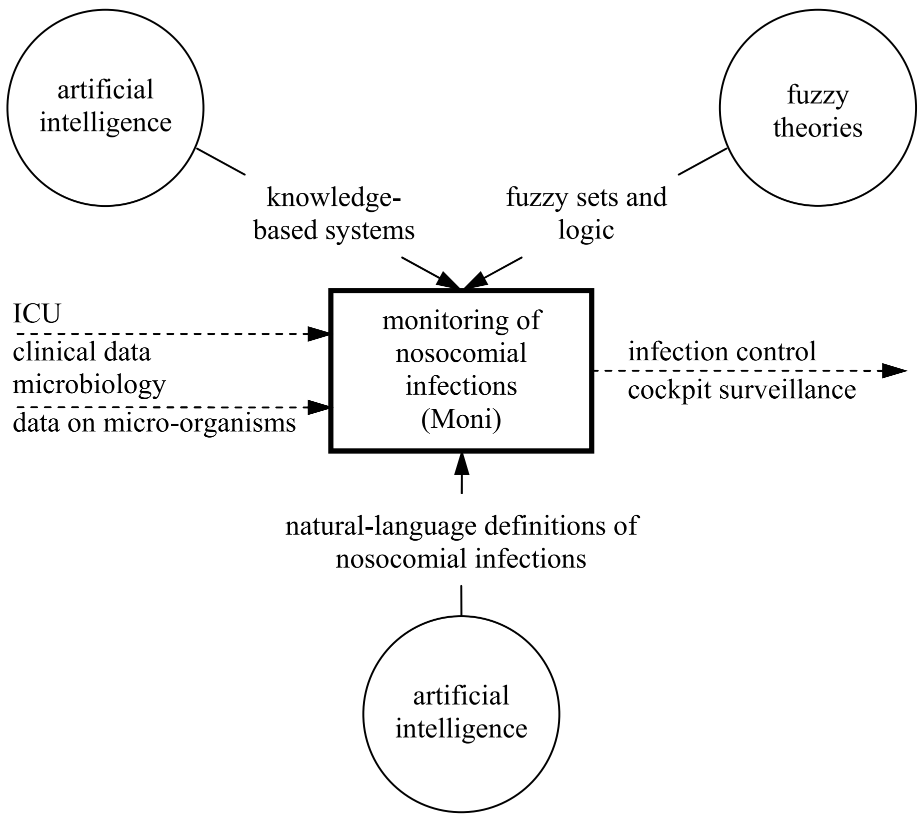

Figure 1. Interplay of the applied formal methods in Moni/Surveillance

The following screenshots show some steps of the Moni surveillance system established for the clinical department of hospital hygiene at the Vienna General Hospital:

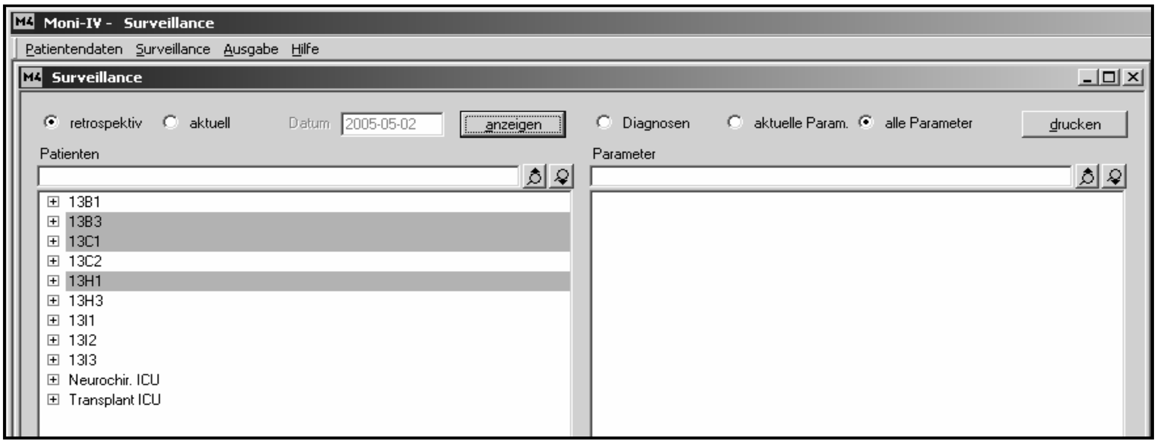

Figure 2. Indication of those ICUs at which patients developed a suspected or confirmed nosocomial infection according to the most recent data. The color codes indicate whether they were suspected cases, i.e., the HELICS definitions of nosocomial infections were only partly fulfilled, or whether they were confirmable cases in which the definitions were completely fulfilled.

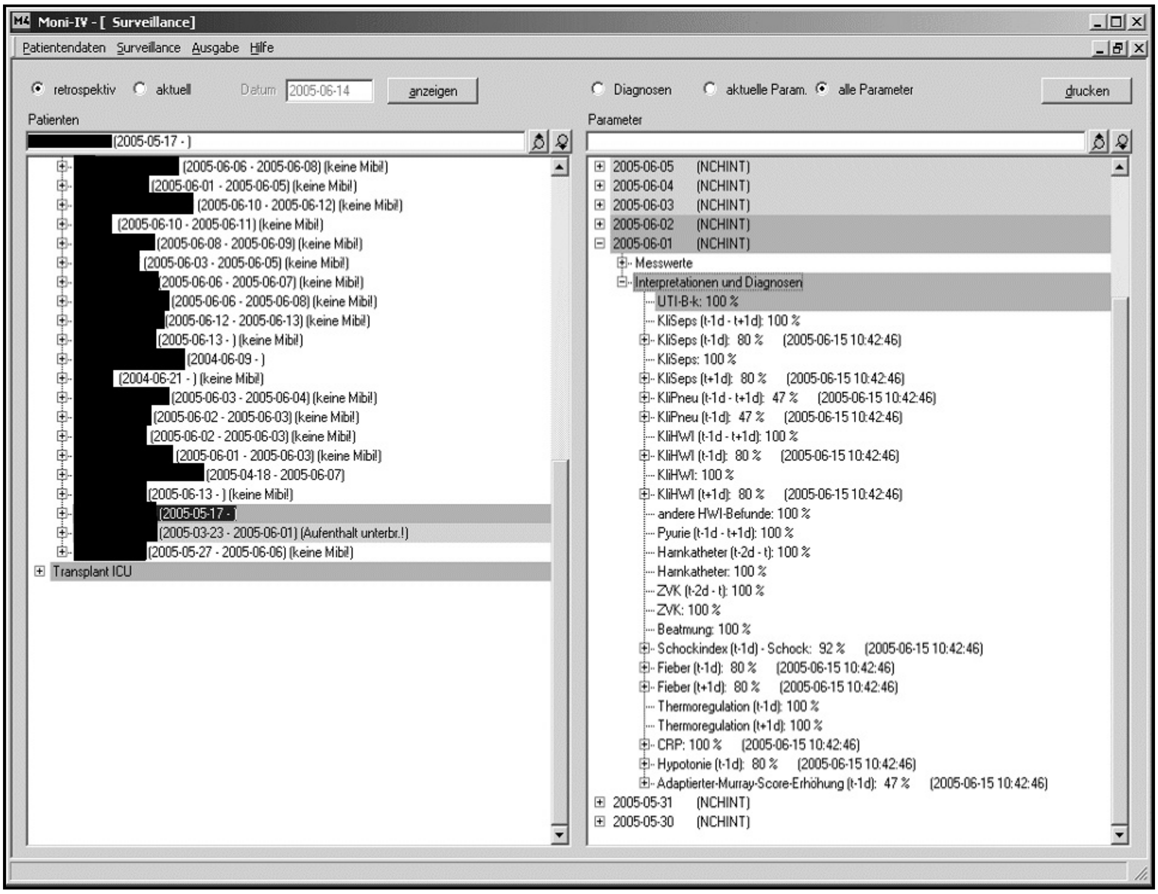

Figure 3. In one patient at the neurosurgical ICU the definition of a catheter-associated symptomatic urinary tract infection (refer to UTI-B-k above right) is fulfilled by 100%; the underlying originally measured and observed patient data and the intermediate medical concepts derived from these data are shown as explanation, if requested

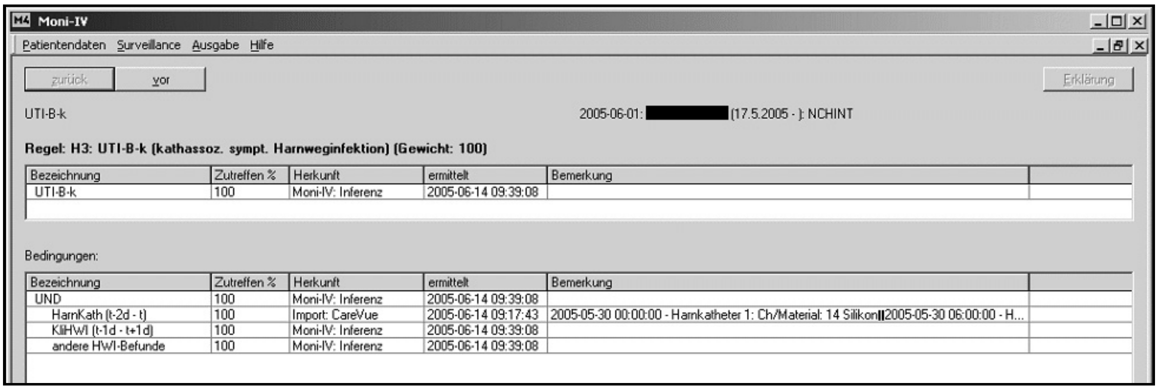

Figure 4. Tracing the logical conclusion chain shows that the patient received a urinary catheter; this data element was documented in the PDMS and passed on to Moni/Surveillance through intermediate steps.

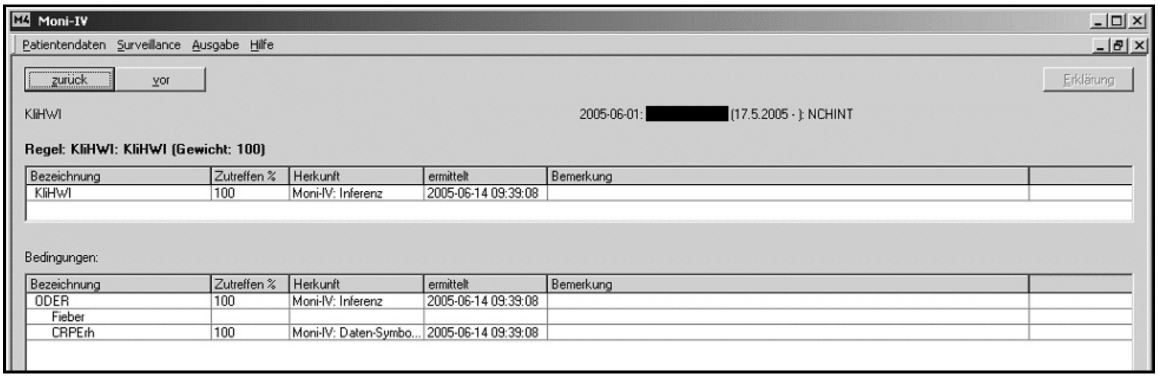

Figure 5. An increased level of C-reactive protein (CRP) is present 100% as a clinical symptom because a determined value of 6 mg/dl (see Figs. 6 and 10) is definitely an elevated value.

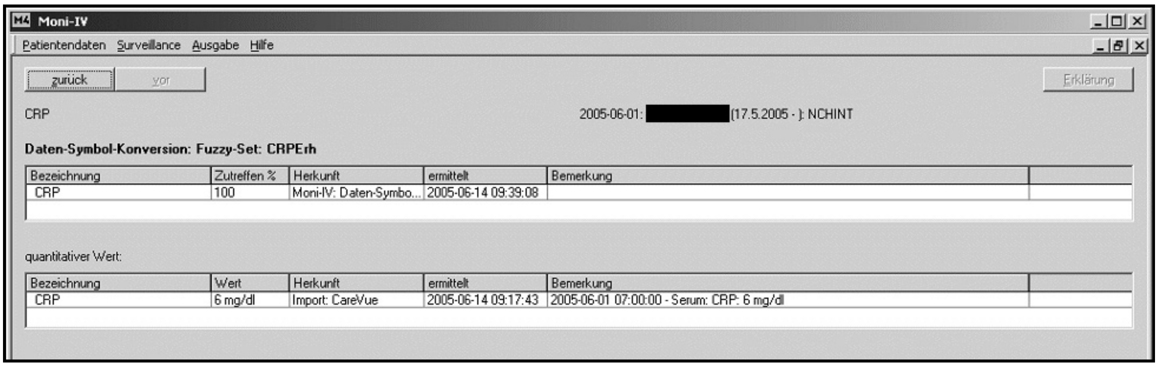

Figure 6. A measured CRP value of 6 mg/dl definitely (100%) signifies increased CRP

4. Methods

Figure 8 shows the implementation of a part of the definition of septicemia of the HELICS document [5] into a formal rule. This—like all other definitions of nosocomial infections—exists in natural language. It is “primary septicemia with clinical signs of sepsis and two-fold common skin germs in blood.” The elements of this rule are decomposed into their constituents (Fig. 9). They contain a number of sub-definitions of clinical and microbiological concepts that are finally evaluated by importing data from both, the PDM systems of the Vienna General Hospital and the LIS of the microbiology department. Some of these concepts, as can be seen in Figure 10 based on the example of “CRP increased”, are defined as fuzzy quantities.

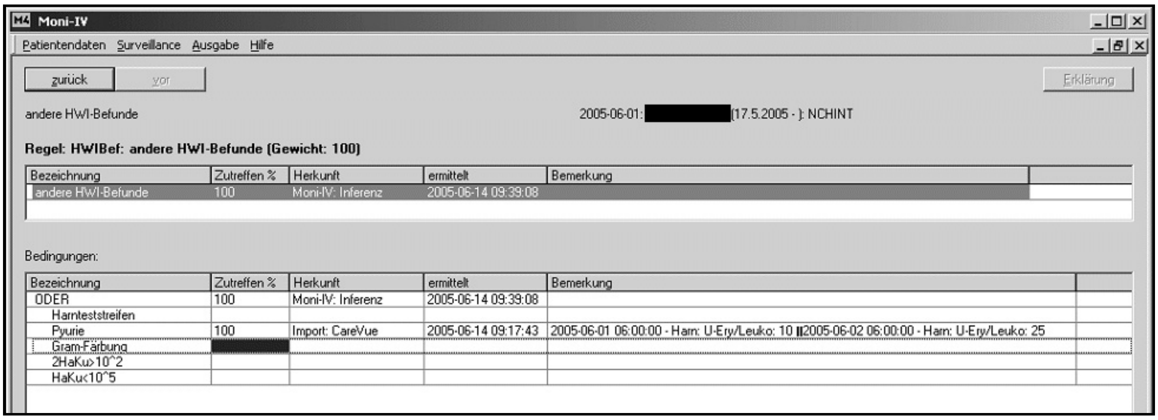

Figure 7. “Other findings of a urinary tract infection” can be fulfilled by several means; here pathogens were found in urine.

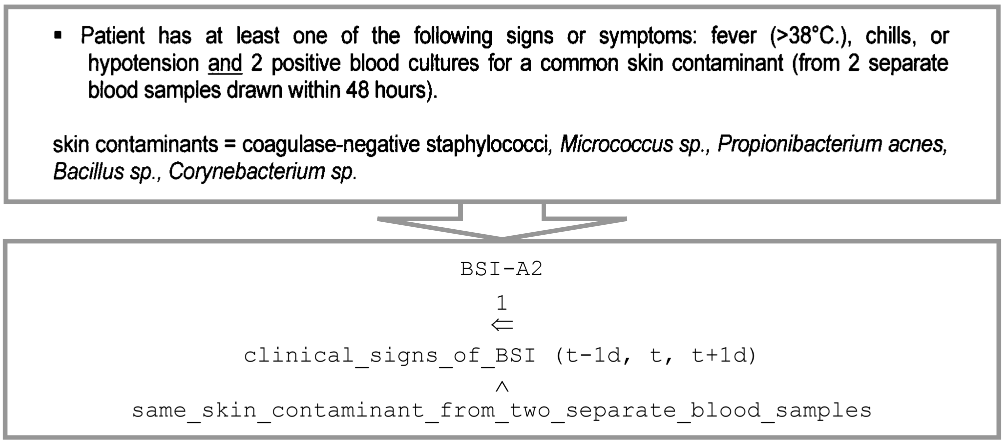

Figure 8. Definition of septicemia with its top level concepts that need to be further decomposed into their constituents.

When the medical data of a specific patient are mapped in, the individual fuzzy concepts are processed and combined through fuzzy logic.

Technically, the rules and concept definitions are represented by using the Arden representation scheme [7]. Arden is a medical knowledge representation and rule-based inference standard supported by HL7 [8]. The basic building blocks of Arden are so-called medical logic modules (MLMs). Each of these modules is usually responsible for one action to be taken on the basis of incoming medical data of a particular patient. Such an action may be an allergy alert, a recommendation for a change in the drug dose, etc. For Moni/Surveillance we created larger building blocks or so-called medical knowledge packages (MKPs). They consist of a number of interwoven MLMs, each contributing to the overall task. Within these MKPs, there are MLMs for simple mapping and pattern matching tasks, others for aggregating detailed information, and yet others for the final logical inference steps. At present 47 MLMs form the MKP for Moni/Surveillance. An

Arden rule engine residing on an Arden server attached to a database with patient data from the connected ICUs holds and processes the MKPs, or MLMs respectively (see also [9]).

```
clinical_signs_of_BSI (t-1d, t, t+1d)

          =
                                                   fever (t-1d)
                                                        ∨
                                                   hypotension (t-1d)
                                                        ∨
clinical_signs_of_BSI (t-1d)          =            leucopenia (t-1d)
                                                        ∨
                                                   leucocytosis (t-1d)
                                                        ∨
                                                   CRP increased (t-1d)
          ∨
                                                   fever (t)
                                                        ∨
                                                   hypotension (t)
                                                        ∨
clinical_signs_of_BSI (t)             =            leucopenia (t)
                                                        ∨
                                                   leucocytosis (t)
                                                        ∨
                                                   CRP increased (t)
          ∨
                                                   fever (t+1d)
                                                        ∨
                                                   hypotension (t+1d)
                                                        ∨
clinical_signs_of_BSI (t+1d)          =            leucopenia (t+1d)
                                                        ∨
                                                   leucocytosis (t+1d)
                                                        ∨
                                                   CRP increased (t+1d)
```

Figure 9. Decomposition of the concept of "clinical signs of septicemia" for today (t), yesterday (t-1d), and tomorrow (t+1d) (for retrospective studies).

5. Results

Currently we have implemented 24 fully computer-based definitions of nosocomial infections as they occur in adult ICU patients according to the European surveillance system HELICS [5]. There are six forms of septicemia, nine forms of pneumonia acquired at the ICU, six forms of urinary tract infection, and three forms of central venous catheter-induced infection.

At present, twelve ICUs with adult patients at the General Hospital of Vienna, comprising 96 beds in all, are connected to Moni/Surveillance. In a currently ongoing test and fine-tuning phase, the system is being evaluated and optimized.

The results obtained thus far not only demonstrate the technical feasibility of the system; the medical results already show that it is an exceptionally valuable means of identifying clinical cases of nosocomial infection in an automated manner (currently such identification is performed by the infection control personnel).

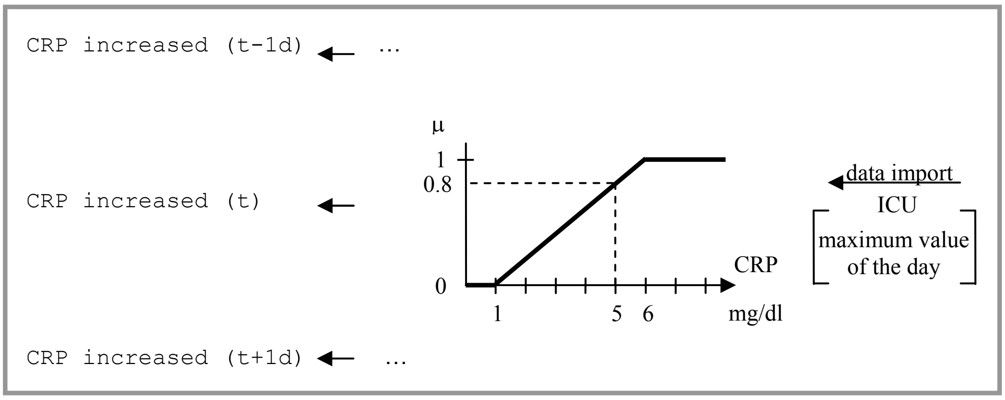

Figure 10. The medical concept of "CRP increased" is defined by a fuzzy quantity. Under 1 mg/dl "CRP increased" = 0, i.e., it is not fulfilled. At 3.5 mg/dl "CRP increased" = 0.5, i.e., it is fulfilled to a certain extent (here by 0.5). A CRP value of 6 mg/dl and beyond means "CRP increased" = 1 and thus the medical concept is completely fulfilled.

6. Conclusion

By applying methods of artificial intelligence and fuzzy theory, the existing identification and monitoring program Moni/Surveillance has been equipped with knowledge-based intelligence that performs complex analytical steps automatically, substantiates these, and thus renders them comprehensible and reproducible.

We believe that routine application of this program will make a significant contribution to quality management at the Vienna General Hospital. In particular, it will assist the treating physicians in reducing the rate of nosocomial infection at the ICUs and may therefore potentially serve as a significant cost-reducing measure.

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