Creation of dosage for induction in anesthesia using Rule-Based System

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***Abstract* — It is a common thing that some consequences will be introduced by the doctor's actions/inactions before, during, or after the surgery. Considering wrong dosing in anesthesia the most common mistakes are caused by doctors' fatigue and inexperience, or by insufficient information included in the dose consideration. This paper proposes software solutions for improving the current state of the models in anesthesia by allowing cooperation between doctor and expert system. Integrating expert knowledge and experience within the rule-based system to guide doctor decisions can produce a safer dosing result, and reduce the percentage of occurrence of side effects. The system recommends the dosage in anesthesia and gives all relevant parameters for the displayed set of the models. The system is based on rules, which can be changed and supplemented, while the system is in production. In the current state, the proposed application can be thought of as a support system for the anesthesiologist, not their replacement.**

***Keywords* — Expert system, knowledge-based systems, Drools, anesthesiology, dosage**

I. Introduction

Anesthesiology is the most aggressive medical discipline. It takes away the consciousness, breathing, and mobility of the patient. This field in medicine constantly strives to learn about the changes caused during and after the surgery (by anesthesia itself) in complex biological structures. Anesthesiology has gained experience for almost two centuries, as it became independent as a particular medical branch. The anesthesiologist takes care of the organism as a whole. The distribution of its' attention is widespread and must include several tasks. One of the most important is constant monitoring of variables that describe the patient's condition [1]. Anesthesiology implies analgesia, in other words, loss of sensitivity to pain. In addition to this, general anesthesia involves loss of consciousness. It is worth mentioning that there is no perfect anesthetic drug. There is an increasing emphasis on balanced anesthesia, which includes using narcotics to induce sleep, analgesics to prevent a reflex response to pain, and muscle relaxants to relax skeletal muscles. Each of them is used in the smallest dose to achieve the desired effect, to recover consciousness of the patient within a few minutes after surgery, and without the side effects.

Anesthesiology is an enormous branch that consists of induction, maintenance, and waking up from anesthesia [2]. The anesthesiologist decides on the safest plan of anesthesia for a given surgery and a given patient. Overestimating or underestimating the dose is not uncommon and can lead to an overdose or sub-dose (awakening) of the patient during surgery. The awakening of the patient can be solved in seconds by increasing the dosage, which is not a problem. The problem is overdose because it leaves temporary or permanent consequences, and in the worst case, death. Experience is needed to put patients to sleep and wake up from anesthesia without unwanted reactions. Although experience sometimes is not a crucial factor for mistakes, sometimes it can be caused by fatigue or not considering all relevant parameters in making the decision.

This paper aims to support the anesthesiologist during the induction in anesthesia, more precisely preventing the patient from being put at risk by administering an inadequate anesthesia plan. The idea is that the anesthesiologist and the software solution work together during the surgery. The software solution would take care of the specifics of the patient to calculate and propose the best proportion of drugs. The final decision is still on the anesthesiologist guided by his knowledge, feeling, and experience.

In the knowledge-based system [3], we can group key segments of patients and anesthesia in one place. The system is primarily intended for anesthesiologists as a web application. Rules in the system are written in Drools [4]. By relying on the application, the surgery can be performed to a certain level only with medical technicians experienced in anesthesia whereas an anesthesiologist is doing only supervision.

The following section defines the research questions and methodology. The third section provides an overview of related works. The analysis of existing solutions is described in the fourth chapter. The software solution design is in the fifth chapter. The sixth chapter states the implementation specifics. The last chapter discusses systems improvements and possible future work.

II. RESEARCH QUESTIONS AND METHODOLOGY

The research in this paper will try to answer to 2 questions:

- Is it possible to make a support system for the creation of dosage for induction in anesthesia by relying on the patients' general condition and history?
- If so, can the creation of dosage be done by using a rule-based system where domain knowledge is stored in the form of some formally defined rules?

The methodology consists of the following:

- Review of related work concerning expert systems that are designed to solve problems mimicking the human experts in the field of anesthesia and medicine. There are many references to how formally defined rules have been used to represent expert knowledge.
- Analysis of some of the existing popular applications that are used for making dosage decisions.
- Collection of the domain knowledge from the field of anesthesia that will include consultation with field experts and consulting books.
- Choosing an appropriate rule-based system.

III. RELATED WORK

Considering all affecting factors, making medical decisions can be time-consuming and cause inertia. Hence there is a need for reliable means to improve the choices of used drugs.

In these situations, expert systems [5] and systems based on rules can become relevant and helpful because they can store large amounts of knowledge, which may be accessed quickly and manipulated easily.

Article [6] presents a system based on rules to process defuzzification to control the depth of anesthesia and decide the required dose of the anesthetic drugs.

In [7], a surgery simulation solution was introduced that allows anesthesiologists to practice critical events for anesthesia. The expert system interprets the patient information, differential diagnosis, and treatment of abnormal patient conditions.

The authors of [8] have created the expert system for dosing in local anesthesia and vasoconstriction supplements in spinal anesthesia.

Using a rule-based system to support alarms during dosing of anesthesia is stated in the paper [9].

Paper [10] describes the usage of fuzzy logic in medical applications. The advantages and benefits of knowledge-based and fuzzy expert systems are utilized to solve some problems. Problems are the diagnosis of diseases, mixed diagnosis, the optimal selection of medical treatments, and real-time observing of patient data.

The paper [11] presents an adviser for anesthetic control and intensive care using an adaptive neuro-fuzzy inference system and certainty factors. The system uses generic rules and trains data with neural networks.

An expert system in [12] proposes diagnosis and treatment of nephrolithiasis where knowledge is stored as rules in the system knowledge-base. The system will work if experts are not available at that moment.

Most of the mentioned works and applications are usually focused on solving one narrow well-defined problem. It is usually the depth of the anesthesia and the preoperative training of critical situations during the dosing. Some of the discussed papers are working with general formulas fixed in rules, and do not have any chance to improve the existing model of drugs.

The software solution proposed in this paper will offer all relevant, sorted doses for a particular patient, supporting the monitoring process if an external application can supply real-time data for induction into anesthesia. It has reporting module that contains logs and alarms generated if an abnormal patient's reactions occur. The application can check for hypotension and low blood pressure, which is usually an indicator that the patient has overdosed.

IV. ANALYSIS OF EXISTING SOLUTIONS

An analysis of three popular solutions from the aspect of usage is done to identify the basic requirements and desirable features for the proposed solution. An analysis of their implementation is omitted - proprietary software. The analyzed solutions are Anesthesiologist [13], Anesthesia Assist [14], and Online Anesthesia [15].

A. Anesthesiologist and Anesthesia Assist

Anesthesiologist and Anesthesia Assist applications as input require weight and age. An output from the first one provides all possible drugs that can be used for induction in anesthesia, shown in format: name of medicine - dose. The second application has the same wide range of drugs and recommends maintaining the depth of anesthesia throughout the operation. Both applications only can be used as support for general anesthesia before surgery.

B. Online Anesthesia

Online Anesthesia provides a comprehensive analysis of surgeries. Application filters the history of surgeries by many parameters (operation's duration, gender, risk group, type of operation, anesthesia, etc.), resulting in patients' surgical records that have a similar condition. The goal of the application is to give insight into the specifics of a given patient's surgery.

C. Summary

The first two solutions include a large set of medications and their combinations for anesthesia dosing. Both applications work on a global level and disregard any patient's specificity. The third application relies on the previous history of user surgical data. As previously mentioned, all of the applications are only pre-operative applications for supporting the calculation of dosage.

V. Software solution design

Previously discussed existing solutions are either desktop, web, or mobile applications. We have decided that our software solution should be developed as a web application because this approach is becoming increasingly common these years – web applications are accessible from any device with a browser and offer a good user experience. The user roles that should be supported by our software solution are the anesthesiologist, admin, and patient, which are the roles identified in the analyzed system.

The patient can review his surgical history.

The administrator role is related to user management (delete, register, and modify), the creation of instances for anesthesia models and anesthesia, and application security maintenance.

The focus of the application is on the anesthesiologist role. The anesthesiologist can initiate the scheduling of a new surgery and acquisition of recommendations about dosage for induction in anesthesia.

For the induction in anesthesia, if an external application is supplying real-time data to the system, then the anesthesiologist's role is extended with some monitoring functionalities (tracking of parameters during the induction in anesthesia, abnormal condition detection, acquisition of drug dosage suggestions for current patient's condition, etc.). In a scenario where the current patient's parameters are not within a range of average, the alarming rules will be activated, and the application will alert the anesthesiologist.

Domain knowledge of anesthesia and drugs should be implemented by storing knowledge within the rules, using the rule-based system. The knowledge-based system will store domain knowledge about dosing, monitoring, and reporting. Dosing knowledge is the most complex, it provides a dosage of drugs according to the patient's condition and dosing standards. Monitoring knowledge concludes current patient status by relying on collecting the patients' reactions to the proposed dosage. Reporting will allow the doctor to have an insight into previously-stored reactions.

The proposed software solution has three sets of functionalities: the one which is responsible for creating the surgery in the system, the other that works with patient parameters, and the last one for the safety of the application.

VI. System implementation

The system is implemented as a client-side web application that contains the front-end application (Angular), server application (Spring Boot), rules-based application (Drools), and database (PostgreSQL). The implementation of the system is accessible on https://github.com/Andjelaaa/SBNZ, and a short video demonstrating its' usage is available on https://www.youtube.com/watch?v=nYZ5eUsOMdU.

Construction of the knowledge base for the rules-based application is done by consulting with domain experts and by the review of [2]. Consultation with experts was via a Face-to-face interview, paper questionnaire, electronic questionnaire, and conceptual modeling.

Domain knowledge is stored formally in a machine-readable format by writing rules. The rules are stored in a rules-based application apart from the server application, so domain experts can modify them without interrupting the application. In this way, domain experts can manage the knowledge base without knowing the rest of the system.

The most important groups of rules are explained below. The first group of rules is for determining the dose of the drug. Complex Event Processing (CEP) [16] rules for the monitoring of hypotension are in the second group. Reporting is in the third group of rules.

A. Determining a set of rules for dosing

The dosing rules consider all possibilities, steering towards perfect dosing. In the current implementation, the forward-chaining relies on six stages, each with its' set of rules.

The first stage concludes the severity of the operation. Depending on whether it is an open surgery or minimally invasive surgery. When one of the previous rules is satisfied, the second stage of reasoning follows.

The second stage of reasoning is for calculating the risk group of surgery. The rules are mutually exclusive. It means that patients can belong just to one risk group. Knowledge is based on ASA I / II / III / IV [17] risk groups. Accordingly, the rules for five different risk groups are GROUP 1, GROUP 2, GROUP 3, GROUP 4, and GROUP 5. The rules are triggered depending on satisfying the group facts. Fact-checking starts from the fifth group to the first group, respecting descending order. Patient classification from V to I group, is indicated by facts:

- Moribund patients (patients are in the state of dying and are not expected to survive without surgery). The facts from this part are major-craniocerebral trauma with rapidly growing, massive pulmonary embolism, and ruptured abdominal aneurysm with deep shock.
- A severe life-threatening systemic disorder. Data are collected from the questions for the following illness: unstable angina pectoris, heart attack (not older than six months, examination in the history of the disease), moderate-severe pulmonary insufficiency, advanced pulmonary-hepatic insufficiency, and organic heart disease. Most of them are collected from the ECG/ultrasound and the patient's history.
- The severe systemic disorder/disease. It can be caused by severe organic heart disease, heart attack (older than six months, examination in the history of the disease), stable angina pectoris, moderate-severe pulmonary insufficiency, severe diabetes mellitus with systemic complications (value greater than sixteen).
- Lacquer - moderate systemic disorder. The facts are easy diabetes mellitus, essential hypertension, extreme obesity, and chronic bronchitis.
- A healthy patient is a patient without organic disorders, biochemical disorders, and mental disorders.

The third stage rules depend on the type of surgery, defined in the first stage of reasoning. There exists one rule for open surgery and two rules for minimally invasive surgery. The results of the first rule are general anesthesia drugs like propofol and sevoflurane. If the patient is kept awakened, the second and third rule differs in the duration of surgery. If the estimated time of the operation is less than 1 hour, then the suggested drug for local anesthesia is lidocaine. If surgery time is greater than 1 hour, then the medication is local anesthesia is bupivacaine. If a patient for minimally invasive surgery asks for total anesthesia, then anesthesia drugs like propofol and sevoflurane are used.

Each of the previous drugs has several models that differ on the age and weight of the patient. All appropriate models will be defined in the fourth stage of reasoning.

The fifth stage is for reducing or increasing the dose for previously selected models. More precisely, if the patient is chronically addicted to drugs/alcoholics, the dose will be increased by 20%, and if he belongs to the ASA III / IV group dose will be reduced by 20%. An example of defining the model is shown in Figure *1* and expresses how the dosage can be determined for patients that are under sixteen years old if they are in critical condition.

The last stage determines the percentual risk of the surgery. The risk of the surgery is estimated by the number of facts satisfied from the patient's general condition and the patient's affiliation to a particular risk group. Each risk group has its ASA formulas calculating the percentual risk of the surgery.

Note: Patients from the fifth risk group do not receive any drugs for induction because they are in a pre-death state. Every kind of medicine in that state will worsen their condition. They will begin to receive the medications after the induction of the anesthesia phase.

B. A set of rules for monitoring events

Rules are used to observe the patient's reaction to drugs and their quantity.

The basic monitoring rules are the rules for internal bleeding (shock), decreased number of breaths, hypoxia (reduced saturation, below 90), hypocapnia (carbon dioxide level below 10), hypercapnia (carbon dioxide level above 45), and Pneumothorax (air in the space between the inner pleura and outer pleura). The combination of triggers for basic rules will trigger the advanced rules. The complex events are Bradycardia (slower heart rate), and Hypovolemic shock (reduced blood volume). The Bradycardia is activated by the low level of the heartbeats and hypoxia. The hypovolemic shock comes from Pneumothorax and inner bleeding. If these three rules are activated, hypotension will be activated.

All monitoring rules are confirmed via simulation of an external application that supplies real-time data for induction into anesthesia.

C. A set of rules for reporting on past surgeries

Next to hypotension, the main thing for future research is reporting sorted patients by the severity of the operation they have had so far.

VII. Conclusion

This paper describes an expert system based on rules, which calculates the appropriate dosage of anesthesia for each patient. The system includes all relevant parameters in the calculation to avoid any side effects.

```
function double calculateDosage(Questionnaire questionnaire, String risk, double val){

    int addict = 0;
    if(questionnaire.isChronicAddict())
        addict += 1;
    if(questionnaire.isChronicAlcoholic())
        addict += 1;
    if(risk.equals("Group 4") || risk.equals("Group 3"))
        addict -= 1;
    double retVal = val;
    if(addict != 0)
        retVal = val + ((val *addict)/5);
    return retVal;
}

rule "Propofol, under 16 years of age"
    no-loop true
    lock-on-active true
    activation-group "propofol"
    when
        $operation : Operation($id:id, $risk:risk, $id == null)
        $patient : Patient($birthDate: birthDate, ChronoUnit.YEARS.between( $birthDate,LocalDate.now()) < 16)
        $list: Models()
        $questionare: Questionnaire()
        $model: AnesthesiaModel($modelName:modelName, $modelName == "Model 1, propofol") from $list.getModels()
    then
        double dosing = calculateDosage($questionare, $risk , $model.getValue());
        $model.setValue(dosing);
        HashSet<AnesthesiaModel> allModels = new  HashSet<AnesthesiaModel>();
        allModels.add($model);
        $operation.setAnesthesiaModel(allModels);
        update($operation);
end
```

Figure 1 Calculate dosage

The software solution is currently in the knowledge gathering phase, and it is appointed exclusively to experts. Also, all knowledge has been collected from a specialist anesthesiologist in writing through appropriate survey methods. The knowledge base contains the expert's knowledge and the application's experience, which could be linked to the programmatic study and the conclusion of further improvement of the model by observing patient specifics and surgery results (in the context of anesthesia).

This paper describes an expert system based on rules, which calculates the appropriate dosage of anesthesia for each patient. The system includes all relevant parameters in the calculation to avoid any side effects.

The software solution is currently in the knowledge gathering phase, and it is intended exclusively for anesthesia doctors.

Further improvement of application can be done regarding the accuracy of dosage calculation.

The accuracy of dosage calculation could be increased by adding new rules and facts, that bring new anesthesia techniques, new drug models, new parameters, etc.

Also, the system can be extended with new roles as medical technicians and specialists from other medical fields. Adding specialists from another medical branch will make the system more independent.

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