Construction of a Clinical Decision Support System for Undergoing Surgery Based on Domain Ontology and Rules Reasoning

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Abstract

Objective: To construct a clinical decision support system (CDSS) for undergoing surgery based on domain ontology and rules reasoning in the setting of hospitalized diabetic patients. **Materials and Methods:** The ontology was created with a modified ontology development method, including specification and conceptualization, formalization, implementation, and evaluation and maintenance. The Protégé-Web Ontology Language editor was used to implement the ontology. Embedded clinical knowledge was elicited to complement the domain ontology with formal concept analysis. The decision rules were translated into JENA format, which JENA can use to infer recommendations based on patient clinical situations. **Results:** The ontology includes 31 classes and 13 properties, plus 38 JENA rules that were built to generate recommendations. The evaluation studies confirmed the correctness of the ontology, acceptance of recommendations, satisfaction with the system, and usefulness of the ontology for glycemic management of diabetic patients undergoing surgery, especially for domain experts. **Conclusions:** The contribution of this research is to set up an evidence-based hybrid ontology and an evaluation method for CDSS. The system can help clinicians to achieve inpatient glycemic control in diabetic patients undergoing surgery while avoiding hypoglycemia.

Key words: clinical decision support system, ontology, formal concept analysis, diabetes mellitus, surgery, JENA

Background

Diabetes mellitus (DM) is a global health problem. The prevalence of diabetic patients requiring surgery is increasing. Surgery is a physical stress characterized by catabolism, starvation, and glucose intolerance. All of these metabolic effects are exaggerated with diabetes. Anesthetic agents used during surgery may also affect glucose metabolism. Mortality rates in diabetic patients are greater than in nondiabetic patients. Tight glycemic control of hospitalized diabetic patients undergoing surgery with insulin can reduce complications and hospital length of

stay, but it may also induce hypoglycemia. Severe hypoglycemia may increase the mortality rate and cardiovascular deaths. Hypoglycemia can be stopped by reducing the dose of insulin; however, hyperglycemia may happen, too. How to grasp glucose-insulin complexities and the effects of anesthesia and surgery is challenging. A multidisciplinary team is recommended to address this issue.¹

Taichung Hospital is an accredited area hospital and secondary-class teaching hospital in central Taiwan. A multidisciplinary team was established for perioperative glycemic management, including surgeons, anesthesiologists, diabetes educators, nurses, and endocrinologists. A study was carried out from March 2008 to February 2009 in Taichung Hospital. One hundred two diabetic patients admitted for operation were enrolled. Their average age was 58 ± 3 years old, and men accounted for 49% of the population. The average number of days in the hospital was 21 ± 11 days. Hypoglycemia has been defined as any blood glucose level of <70 mg/dL, and severe hypoglycemia was defined as <40 mg/dL. Among 3,607 glucose measurements, hypoglycemia was found in 0.4%, and severe hypoglycemia was only 0.03%. These values were even better than those in a previous study in which severe hypoglycemia accounted for 3%; this study indicated the frequency of severe hypoglycemia in the inpatient population with diabetes undergoing surgery was effectively reduced.²

Under normal circumstances, endocrinologists visit the diabetic patient preoperatively and give insulin orders. However, physicians are very busy because of their heavy workloads. When endocrinologists are not present, other team members must take charge of insulin orders. Although the American Diabetes Association has made some recommendations for diabetes care in the hospital, they may be modified to suit the clinical use. In Taichung Hospital the flow-chart for management of DM during surgery, which is displayed in Appendix 1, was developed. However, it is not easy because of the complexity of writing insulin orders and the fear of inducing hypoglycemia by trying to achieve recommended goals. Moreover, there are many successfully treated cases stored in the medical records. These experiences can be retrieved and reused to improve the medical quality.

A clinical decision support system (CDSS) can help physicians make decisions and improve quality of healthcare.³ Knowledge representation in the medical domain is a key issue for knowledge to be effectively used for reasoning as a part of the CDSS. An ontology is a model of a particular field of knowledge—the concepts and their attributes, as well as the relationships between the concepts.⁴ Ontologies describe and organize domain knowledge in a manner machines can read and humans can understand, so decision support may be promoted with

computer-based systems or applications.^{5,6} Ontologies also may help the development of CDSSs in a way to enhance the reusability of data and knowledge. Clinical knowledge sharing, update, and reuse are the advantage of an ontology-based CDSS.

Recently medical informatics has concentrated on how to develop evidence-based decision support tools to provide relevant and up-to-date evidence to clinicians due to the advance of evidence-based medicine.⁷ Previous studies have shown that the clinicians hoped to access and retrieve patient-related data to support their clinical practice and clinical research.^{8,9} Formal concept analysis (FCA) is a mathematical method of data analysis based on the lattice theory. Jiang et al.¹⁰ used FCA to support the construction of a context-based ontology in the clinical domain. The knowledge embedded in the medical records may be elicited to complement the domain knowledge with FCA. The aim of this study was to build an ontology-based CDSS to generate evidence-based recommendations for diabetic patients in the setting of perioperative glycemic management.

Materials and Methods

OVERVIEW

The overall architecture of the evidence-based hybrid ontology in the CDSS for diabetic patients undergoing surgery is illustrated in *Figure 1*. First, a domain ontology pertaining to the management of DM during surgery was built using the Protégé-Web Ontology Language (OWL) editor. Then, FCA was used to discover knowledge embedded in the database, which consisted of 402 medical records. The elicited knowledge was added to the domain knowledge. Subsequently, the decision rules were translated into JENA rule syntax, which could then be input to the JENA reasoning system. JENA used the rule set to infer recommendations based on patients' profiles. A patient database that included de-identified patient clinical situations of the patient class in the ontology was created for evaluation. A graphical user interface with which clinicians can interact was provided. One domain expert, an endocrinologist, was recruited to participate in the construction and evaluation of the ontology. The Taichung Hospital Institutional Review Board approved all of the research procedures. All user evaluations were conducted in a laboratory setting.

For implementing this system, four tools/languages have been used: OWL description logic (DL), Protégé, "Concept Explorer" (ConExp), and JENA rules. OWL¹¹ is one of the most used standard ontology languages today. OWL is applied when information is not only presented, but also needs to be processed. OWL ontology consists of classes, properties, and individuals. Classes represent a spe-

Fig. 1. Proposed system architecture. API, application programming interface; FCA, formal concept analysis.

cific clinical concept in the domain. OWL DL was chosen because it provides users with the maximum expressiveness while retaining computational completeness and decidability.

Protégé, which was developed by Stanford Medical Informatics (Stanford, CA), is an actively maintained open source application. It supports automated reasoning tasks such as consistency checking and automatic classification of classes using DL expressions.¹² The Protégé-OWL editor¹³ was selected because it is an extension of the Protégé platform and enables the creation and representation of ontologies in OWL in one step.

The ConExp tool was developed under the supervision of Prof. Dr. Tatyana Taran in 2000.¹⁴ It was extended and now is an open source project on Sourceforge. ConExp implements basic functionality needed for study and research of FCA, including context editing, building concept lattices from context, finding bases of implications that are true in context, finding bases of association rules that are true in context, and performing attribute exploration.

JENA, which is built on the platform-crossing language Java and open source, is made by HP Labs (Palo Alto, CA). JENA is a general-purpose rule-based reasoner and supports rule-based inference over RDF graphs.¹⁵ This reasoner provides forward chaining, backward chaining, and a hybrid execution model. The JENA inference engine

was selected as a reasoner because it is the most popular and stable framework to compute and manage RDF/OWL descriptions.

We adopted a modified version of a four-stage approach for an ontology-based information system designed by Kuziemy et al.¹⁶: specification and conceptualization, formalization, implementation, and evaluation and maintenance.

SPECIFICATION AND CONCEPTUALIZATION

Existing ontologies relevant to our topic are quite rare. The domain development of our ontology was based on the flowchart for management of DM during surgery implemented in Taichung Hospital. The clinical scope of the ontology was guided by the domain expert.

FORMALIZATION

Domain ontology development. A top-down approach was used to create the classes. We introduced higher-level classes first, and then medium- and lower-level classes. For example, we started with a general concept of Management before defining subclasses such as Medication. After classes were created, properties were added, and finally individuals were completed.¹⁷ The process of ontology building is iterative, and the ontology was revised and refined by the domain expert.

We have three main classes in this ontology: Disease, Management, and Patient. The Management class is further subdivided into six subclasses: Anesthesia, Capillary Glucose tests, Control of DM, Medication, No Medication, and Water Restrictions. The Disease class consists of two subclasses: Diabetes and Comorbidity. *Figure 2* displays a screenshot of some of the ontology classes. In our system, the Patient class has no subclasses but has some relations with other classes like Medication, Diabetes, and Control of DM.

Classes can contain individual objects called individuals. There are two main types of properties: Object properties and Datatype properties. Object properties link individuals to individuals. Datatype properties link individuals to data values. Each property has a domain and a range. The domain and range of an Object property and the domain of a Datatype property are defined by classes, but range of a Datatype property is an XML Schema Datatype value or an RDF literal. *Table 1* presents some of the properties in the system.

We applied the singleton pattern to the individuals of the Medication class because it does not make sense to have many individuals under medical measures.¹⁸ Each class can only have one individual, which can avoid confusion while expressing facts. *Figure 3* shows the singleton pattern.

Elicitation of implicit knowledge. From March 2008 to November 2010, in total, 307 diabetic patients were admitted for surgery in Taichung Hospital. During this period, 402 serial discharge summaries were collected and stored in a database. Some patients have more than one discharge summary because they were admitted to the hospital for surgery again. The patient names were carefully removed from the discharge summaries for privacy. The formal object is made up of medical records stored in a database. The formal attribute

Fig. 2. Screenshot of some of the ontology classes. DM, diabetes mellitus; IV, intravenously; owl, Web ontology language.

Table 1. Some of the Defined Properties in the Ontology

PROPERTY NAME	PROPERTY TYPE	DOMAIN	RANGE
Associated Heart Comorbidity	Object	Patient	Heart Comorbidity
Control DM with	Object	Patient	Control of DM
Has Anesthesia	Object	Patient	Anesthesia
Has Water Restrictions	Object	Patient	Water Restrictions
Capillary Blood Glucose Is	Datatype	Patient	Integer
eGFR Is	Datatype	Patient	Float
Sex	Datatype	Patient	String

DM, diabetes mellitus; eGFR, enhanced glomerular filtration rate.

Fig. 3. The singleton pattern. Amps, ampules; DM, diabetes mellitus; G50W, 50% glucose in water; GKI, glucose/potassium/insulin; IV, intravenously; RI, regular insulin; SC, subcutaneously.

includes clinical situation, such as renal function, plasma glucose concentration, and infusion rate of fluid. Because an attribute may have many values, the context is also many-valued. In order to extract concepts out of this many-valued formal context and further draw the concept lattice, the many-valued context was transformed to a one-valued context by plain scaling.¹⁹ In the FCA module, a formal context with 402 objects (medical records) and 26 attributes (medical situation) was formed. Because complexity is a major problem for a concept lattice display, the whole concept lattice was not computed based on the whole context. In order to reduce the complexity to a certain degree, the concept lattice was only constructed by some medical concepts (here attribute) according to the interest and selection from a domain expert. Figure 4 displays part of the formal context of the database, and Figure 5 shows part of the Context information displayed by the formal concept lattice in ConExp.

A set of implications between attributes can be identified from the concept lattice in ConExp. These implications are what we call dependence rules. The de-

pendence rules extracted from the lattice may be added into the ontology to complement the domain knowledge, for example, "Stage 4 → KCl-0" (as shown in Fig. 6). A dependence rule extracted from the lattice indicates that in the database, all diabetic patients with chronic renal disease Stage 4 are not supplemented with potassium chloride. Figure 6 shows part of the attribute implication information displayed in ConExp.

Formalization of rules. JENA is an RDF application programming interface in Java, for the creation and manipulation of RDF graphs. An RDF graph is simply a set of triples (S, P, O), where P names a binary predicate over (S, O). Variables in the RDF triples have a "?" as prefix. We wrote the rules by using the JENA rule syntax.¹⁵ Three examples of rules are presented in Table 2, and other examples are provided in Appendix 2.

IMPLEMENTATION

A patient database that included a de-identified patient clinical profile for 20 fictitiously named individuals of the patient class in the ontology was created to evaluate the JENA rules in generating the recommendations. The patient data were manually entered in Protégé. An easy-to-use graphical user interface (Fig. 7) was created so

Fig. 4. Part of the formal context of the database.

Fig. 5. Part of the Context information displayed by the formal concept lattice in “Concept Explorer.”

that data entry was easy for clinicians, and the recommended result can be displayed through the interface.

An example recommendation for one test case, based on the JENA rules listed in Table 2, is shown in Figure 7 for illustration. A 68-year-old female patient has type 2 DM and chronic kidney disease Stage 3B but does not have heart failure or hepatic failure. DM was controlled with DM diet and oral antidiabetic drugs. Her laboratory results on admission are as follows: fasting glucose, 72 mg/dL; nonfasting glucose, 96 mg/dL; hemoglobin A1c, 6.4%; Na, 138 mEq/L; K, 4.2 mEq/L; creatinine, 1.38 mg/dL; and enhanced glomerular filtration rate, 36 mL/min. She will have an operation under spinal anesthesia. Now capillary blood glucose is 49 mg/dL. What will be recommended for her? The recommendations made by the system are as follows: (1) Give 50% glucose water (2 ampules intravenously immediately). (2) How long before the blood sugar level must be rechecked? (1 hour). The system can make recommendations that conform to logic rules.

EVALUATION AND MAINTENANCE

The developed ontology-based CDSS prototype was evaluated by 12 clinicians, including three endocrinologists, three attending physicians (one surgeon, one medical doctor, and one anesthesiologist), three residents (one surgeon and two medical

1 < 4 > Stage 4 ==> KCI-0;
2 < 1 > K-1 ==> Stage 3B KCI-10;
3 < 1 > K-3 ==> Stage 4 KCI-0;
4 < 1 > Stage 3B KCI-0 ==> K-2;
5 < 1 > KCI-5 ==> Stage 3B K-2;
6 < 3 > KCI-10 ==> Stage 3B;
7 < 1 > KCI-20 ==> Stage 3B K-2;
8 < 0 > Stage 3B K-2 KCI-0 KCI-20 ==> Stage 4 K-1 K-3 KCI-5 KCI-10;
9 < 0 > Stage 3B K-2 KCI-5 KCI-20 ==> Stage 4 K-1 K-3 KCI-0 KCI-10;
10 < 0 > Stage 3B K-2 KCI-10 KCI-20 ==> Stage 4 K-1 K-3 KCI-0 KCI-5;
11 < 0 > Stage 4 K-2 K-3 KCI-0 ==> Stage 3B K-1 KCI-5 KCI-10 KCI-20;
12 < 0 > Stage 3B Stage 4 K-2 KCI-0 ==> K-1 K-3 KCI-5 KCI-10 KCI-20;
13 < 0 > Stage 3B K-2 KCI-0 KCI-5 ==> Stage 4 K-1 K-3 KCI-10 KCI-20;
14 < 0 > Stage 3B K-2 KCI-0 KCI-10 ==> Stage 4 K-1 K-3 KCI-5 KCI-20;
15 < 0 > Stage 3B K-2 KCI-5 KCI-10 ==> Stage 4 K-1 K-3 KCI-0 KCI-20;
16 < 0 > Stage 3B K-1 K-2 KCI-10 ==> Stage 4 K-3 KCI-0 KCI-5 KCI-20;

Fig. 6. Part of the attribute implication information displayed in “Concept Explorer.”

doctors), and three nurse practitioners. First, participants evaluated the acceptance of recommendations with a 5-point (from strongly disagree to strongly agree) survey. These recommendations were made according to medical data records for 20 de-identified patients in the patient ontology by the CDSS prototype. Afterward, participants completed a modified version of an eight-question, 5-point (from strongly disagree to strongly agree) survey in terms of perceived usefulness,²⁰ satisfaction degree,²¹ and behavioral intentions to use²² (Appendix 3). All the scores were expressed as a percentage, too. The feedback given by the clinicians will be used for the maintenance of the ontology and the prototype.

Results

The designed ontology included 31 classes and 13 properties (seven Object and six Datatype). The correctness of the ontology in representing domain concepts and the relationships among them were confirmed by the domain expert. For our ontology, 38 decision rules were captured and represented as JENA rules.

Table 2. Three Examples of JENA Rules		
NUMBER	RULE	DESCRIPTIONS IN NATURAL LANGUAGE
1	(?x rdf:type Patient) (?x has_Diabetes T2DM)noValue (?x has_Anesthesia Generalized_Anesthesia)noValue (?x Control_DM_with Insulin_Injection)(?y rdf:type No_Medication)→ (?x was_Suggested_to ?y)	If a patient has T2DM and not generalized anesthesia and not insulin injection then no medication is suggested.
2	(?x rdf:type Patient)(?x Capillary_Blood_Glucose_Is ?z) lessThan(?z, 50) (?y rdf:type Glucose_Water) → (?x was_Suggested_to ?y)	If a patient has capillary blood glucose level of <50 mg/dL then glucose water is suggested.
3	(?x rdf:type Patient)(?x Capillary_Blood_Glucose_Is ?z) lessThan(?z, 70) (?y rdf:type Intensive_Monitor) → (?x was_Suggested_to ?y)	If a patient has capillary blood glucose level of <70 mg/dL then intensive monitor is suggested.

T2DM, type 2 diabetes mellitus.

The screenshot shows a software interface titled "Management of Diabetes Mellitus during Surgery" (Version: 2.1). It includes input fields for patient information: Case Load, Date of Admission, Medical Record No., Age (68), Sex (Female), Heart Failure (No), Chronic Kidney Disease (stage 3B), Liver Cirrhosis (No), and Diabetes Type (Type 2). Laboratory and clinical data fields include FBS (72), RBS (96), Cr (1.87), eGFR (36), Na (138), K (4.2), HbA1c (6.4), Weight (56), and Capillary Blood Glucose (49). A "Recommendation" box on the left lists: "1. Give 50% Glucose Water (2 Amps IV stat)" and "2. How long blood sugar level must be rechecked ? (1hr)". On the right, there are dropdowns for "Control DM with:" (Oral Antidiabetic) and "Anaesthesia:" (Spinal Anaesthesia), along with "Add" and "Del" buttons for a list of "DM Diet Control Oral Antidiabetic Drug(s)". A large "Recommend" button is at the bottom center.

Fig. 7. Graphical user interface. Amps, ampules; Cr, creatinine; DM, diabetes mellitus; eGFR, enhanced glomerular filtration rate; FBS, fasting blood sugar; HbA1c, hemoglobin A1c; IV, intravenously; RBS, regular blood sugar.

All participants had at least 3 years of clinical experience and experience using a hospital information system. There were five female and seven male participants. Participants' clinical specialties included internal medicine ($n=8$), surgery ($n=3$), and anesthesiology ($n=1$). Survey data are shown in *Tables 3* and *4*.

Discussion

Clinical guidelines aim to elevate the quality of care, limit unjustified practice variations, and decrease healthcare costs. They may be formalized in order for them to be effective. Computerized clinical guidelines make it possible to develop a CDSS that has a better chance of impacting clinician behavior than narrative guidelines. Only a few ontology-based CDSSs relevant to operations have been developed, such as for preoperative risk assessment and acute postoperative pain management. However, there is none for management of DM during surgery.

This article described the development and evaluation of an evidence-based ontology for a CDSS in the setting of diabetic patients undergoing surgery. In general, a domain ontology is built only based on clinical guidelines for a CDSS. We developed a hybrid ontology that combined both domain knowledge and context-based

knowledge. The domain knowledge of the flowchart can be represented using a domain ontology. For this reason, the properties in a domain ontology and relationships among them could be described explicitly and served as decision support.

Furthermore, the domain-specific context knowledge information was integrated into a domain ontology with FCA, which could identify the relevant medical concepts and the types of their relations. The proposed ontological approach could also be applied to design and develop other ontology-based CDSSs.

It is important to provide relevant and up-to-date evidence for clinicians, which can be accomplished by developing evidence-based decision support systems. FCA can be used to represent and process context knowledge in a clinical domain to

describe patient cases, interpret therapeutic decisions, and represent rules.²³ The knowledge implicitly embedded in the patient medical records database can be captured during the FCA process to complement the domain knowledge.¹⁹ Through this approach, six new concepts and nine new decision rules were elicited, which meets the spirit of evidence-based medicine and can increase the quality of the CDSS.

With regard to measuring the satisfaction of the CDSS, domain experts had the highest score. Domain experts also like using the CDSS in the future, and the system is highly recommended. That indicated that the CDSS has good performance and can play an important role when endocrinologists are absent. The system can assist clinicians in the management of DM during surgery.

Table 4. Survey in Terms of Perceived Usefulness, Satisfaction Degree, and Intentions to Use

PARTICIPANTS	SCORES		
	PERCEIVED USEFULNESS (%)	SATISFACTION DEGREE (%)	INTENTIONS TO USE (%)
Endocrinologists (3)	4.9 (98%)	4.3 (87%)	4.6 (91%)
Attending physicians (3)	3.7 (73%)	3.5 (70%)	3.4 (69%)
Resident physicians (3)	4.0 (80%)	3.8 (77%)	4.3 (87%)
Nurse practitioners (3)	4.3 (87%)	3.2 (63%)	3.2 (69%)

Table 3. Survey in Terms of Acceptance

PARTICIPANTS (N)	ACCEPTANCE (%)
Endocrinologists (3)	4.50 (90%)
Attending physicians (3)	3.6 (73%)
Resident physicians (3)	4.45 (89%)
Nurse practitioners (3)	3.67 (73%)

Although experts have very high acceptance (90%), non-diabetes specialists' acceptance is slightly lower than that of experts. A relative lack of knowledge in the selected domain may explain this phenomenon. Thus, the participants did not have complete confidence to confirm what was recommended by the CDSS. As a result, only two-thirds of clinicians will use this system in the future and will recommend to others. It must be emphasized that the CDSS is not created to replace human clinical decision-making, although a CDSS can effectively support physician performance and improve patient outcomes.³ Some barriers exist between users and information technology, but they can be eliminated through communication and continuous education.

Conclusions

The complexity of writing insulin orders and the fear of inducing hypoglycemia are major obstacles to appropriate inpatient glycemic management. The clinical knowledge of experts can be shared, updated, and reused through an ontology-based system for CDSS. The ontology-based CDSS can help clinicians to overcome these barriers. In terms of evidence-based medicine, the implicit clinical knowledge of medical records can serve as an integral part of a domain ontology, which can provide clinicians with evidence-based recommendations to promote medical quality. This study contributes to understanding the development of an evidence-based hybrid ontology and evaluation methods for CDSS and bridging the gap in ontology-based CDSS.

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Disclosure Statement

No competing financial interests exist.

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Appendix 1: Management of Diabetes Mellitus During Surgery at Taichung Hospital

PREPARATION FOR ADMISSION OF A PERSON WITH DIABETES SCHEDULED TO UNDERGO SURGERY (FIGS. A1–A3)

- Consult the anesthetist on whether the proposed procedure is minor or not.
- Consult diabetes educators to collect the necessary clinical profile and give education.
- Consult the endocrinologist for management of DM during surgery.

MINOR PROCEDURES ONLY

- Flowchart I (*Fig. A1*) for perioperative management of DM
- Capillary blood glucose (CBG) target range: 100–140 mg/dL
 - May run target range higher if hypoglycemic
 - CBG < 70 mg/dL: hypoglycemia
 - Requires immediate treatment as follows: dextrose 50% 2 ampules intravenously immediately, then dextrose 10% intravenous fluid at maintenance rate to prevent CBG fall to < 70 mg/dL
 - CBG > 240 mg/dL: hyperglycemia
 - If hyperglycemia persists in spite of regular insulin at 6 units by subcutaneous injection repeatedly, requires additional insulin—contact the Diabetes Team.

PREOPERATIVE

- Fast from solids from 12 midnight and from fluids from 0400 h.
- Intravenous fluids (NaCl 0.9%) at maintenance rate, starting at 0700 h
- Intravenous fluids with dextrose are not necessary except in hypoglycemia.
- Monitor capillary blood sugars every 2 h, starting at 0700 h.

POSTOPERATIVE: WHILE EATING FOOD

- Give present antidiabetic medications.
- Once the patient is eating/drinking satisfactorily, intravenous fluids can be stopped. Monitor blood glucose as required.
- If intravenous fluids are required for more than 24 h, or blood glucose results are low/high:
 - Discuss with the Diabetes Team.

MORE COMPLEX SURGERY AND EMERGENCY PROCEDURES

- Flowchart II (*Fig. A2*) is recommended.
- Use glucose/potassium/insulin infusion fluid (GKI15).
 - If blood glucose < 120 mg/dL—GKI10.
 - If blood glucose > 200 mg/dL—GKI20.
- Infuse GKI solution at maintenance rate (100 mL/h).
 - If water restrictions needed—reduce infusion rate.
- Add 10 mEq KCl/500 mL of intravenous fluid to avoid hypokalemia.
 - If impaired renal function—reduce the recommended dose of KCl.
 - If hyperkalemia—no supplement of KCl.
- Check CBG every 2 h before, during, and after procedure.
 - Test CBG more frequently if clinically concerned (e.g., hypoglycemic).
- Do not stop insulin infusion completely unless there are problems with persisting hypoglycemia.
 - The insulin infusion should only be stopped for a short period, until hypoglycemia is corrected.
- If using the more complex or emergency surgery protocol—contact the Diabetes Team.

Appendix 2

Appendix Table A1. Examples of JENA Rules	
NUMBER	RULE
1	(?x rdf:type Patient) (?x has_Diabetes T1DM) (?y rdf:type IV_Fluid) → (?x was_Suggested_to ?y)
2	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x has_Anesthesia Generalized_Anesthesia) (?y rdf:type IV_Fluid) → (?x was_Suggested_to ?y)
3	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x Control_DM_with Insulin_Injection) (?y rdf:type IV_Fluid) → (?x was_Suggested_to ?y)
4	(?x rdf:type Patient) (?x has_Diabetes T2DM) noValue (?x has_Anesthesia Generalized_Anesthesia) noValue (?x Control_DM_with Insulin_Injection) (?y rdf:type No_Insulin) → (?x was_Suggested_to ?y)
5	(?x rdf:type Patient) (?x has_Diabetes T2DM) noValue (?x has_Anesthesia Generalized_Anesthesia) noValue (?x Control_DM_with Insulin_Injection) (?y rdf:type No_KCI) → (?x was_Suggested_to ?y)
6	(?x rdf:type Patient) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 300) (?y rdf:type Insulin) → (?x was_Suggested_to ?y)
7	(?x rdf:type Patient) (?x Capillary_Blood_Glucose_Is ?z) lessThan(?z, 70) (?y rdf:type No_Insulin) → (?x was_Suggested_to ?y)
8	(?x rdf:type Patient) (?x has_Diabetes T1DM) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 70) lessThan(?z, 110) (?y rdf:type Low_Insulin_Dose) → (?x was_Suggested_to ?y)
9	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x has_Anesthesia Generalized_Anesthesia) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 70) lessThan(?z, 110) (?y rdf:type Low_Insulin_Dose) → (?x was_Suggested_to ?y)
10	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x Control_DM_with Insulin_Injection) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 70) lessThan(?z, 110) (?y rdf:type Low_Insulin_Dose) → (?x was_Suggested_to ?y)
11	(?x rdf:type Patient) (?x has_Diabetes T1DM) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 110) lessThan(?z, 180) (?y rdf:type Usual_Insulin_Dose) → (?x was_Suggested_to ?y)
12	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x has_Anesthesia Generalized_Anesthesia) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 110) lessThan(?z, 180) (?y rdf:type Usual_Insulin_Dose) → (?x was_Suggested_to ?y)
13	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x Control_DM_with Insulin_Injection) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 110) lessThan(?z, 180) (?y rdf:type Usual_Insulin_Dose) → (?x was_Suggested_to ?y)
14	(?x rdf:type Patient) (?x has_Diabetes T1DM) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 180) (?y rdf:type High_Insulin_Dose) → (?x was_Suggested_to ?y)]
15	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x has_Anesthesia Generalized_Anesthesia) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 180) (?y rdf:type High_Insulin_Dose) → (?x was_Suggested_to ?y)
16	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x Control_DM_with Insulin_Injection) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 180) (?y rdf:type High_Insulin_Dose) → (?x was_Suggested_to ?y)
17	(?x rdf:type Patient) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 70) lessThan(?z, 250) (?y rdf:type Frequent_Monitor) → (?x was_Suggested_to ?y)
18	(?x rdf:type Patient) (?x Capillary_Blood_Glucose_Is ?z) ge(?z, 250) (?y rdf:type Intensive_Monitor) → (?x was_Suggested_to ?y)
19	(?x rdf:type Patient) (?x eGFR_Is ?z) lessThan(?z, 15) (?x Plasma_K_level_Is ?w) greaterThan(?w, 3.3) (?y rdf:type No_KCI) → (?x was_Suggested_to ?y)
20	(?x rdf:type Patient) (?x eGFR_Is ?z) ge(?z, 15) (?x Plasma_K_level_Is ?w) greaterThan(?w, 5.5) (?y rdf:type No_KCI) → (?x was_Suggested_to ?y)]
21	(?x rdf:type Patient) (?x has_Diabetes T1DM) (?x eGFR_Is ?z) lessThan(?z, 15) (?x Plasma_K_level_Is ?w) le(?w, 3.3) (?y rdf:type Low_KCI_Dose) → (?x was_Suggested_to ?y)
22	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x has_Anesthesia Generalized_Anesthesia) (?x eGFR_Is ?z) lessThan(?z, 15) (?x Plasma_K_level_Is ?w) le(?w, 3.3) (?y rdf:type Low_KCI_Dose) → (?x was_Suggested_to ?y)
23	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x Control_DM_with Insulin_Injection) (?x eGFR_Is ?z) lessThan(?z, 15) (?x Plasma_K_level_Is ?w) le(?w, 3.3) (?y rdf:type Low_KCI_Dose) → (?x was_Suggested_to ?y)
24	(?x rdf:type Patient) (?x has_Diabetes T1DM) (?x eGFR_Is ?z) ge(?z, 15) lessThan(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 5.5) greaterThan(?w, 3.3) (?y rdf:type Low_KCI_Dose) → (?x was_Suggested_to ?y)
25	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x has_Anesthesia Generalized_Anesthesia) (?x eGFR_Is ?z) ge(?z, 15) lessThan(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 5.5) greaterThan(?w, 3.3) (?y rdf:type Low_KCI_Dose) → (?x was_Suggested_to ?y)

continued →

Appendix Table A1. Examples of JENA Rules *continued*

NUMBER	RULE
26	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x Control_DM_with_Insulin_Injection) (?x eGFR_Is ?z) ge(?z, 15) lessThan(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 5.5) greaterThan(?w, 3.3) (?y rdf:type Low_KCl_Dose) → (?x was_Suggested_to ?y)]
27	(?x rdf:type Patient) (?x has_Diabetes T1DM) (?x eGFR_Is ?z) ge(?z, 15) lessThan(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 3.3) (?y rdf:type Usual_KCl_Dose) → (?x was_Suggested_to ?y)
28	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x has_Anesthesia Generalized_Anesthesia) (?x eGFR_Is ?z) ge(?z, 15) lessThan(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 3.3) (?y rdf:type Usual_KCl_Dose) → (?x was_Suggested_to ?y)
29	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x Control_DM_with_Insulin_Injection) (?x eGFR_Is ?z) ge(?z, 15) lessThan(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 3.3) (?y rdf:type Usual_KCl_Dose) → (?x was_Suggested_to ?y)
30	(?x rdf:type Patient) (?x has_Diabetes T1DM) (?x eGFR_Is ?z) ge(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 5.5) (?y rdf:type Usual_KCl_Dose) → (?x was_Suggested_to ?y)
31	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x has_Anesthesia Generalized_Anesthesia) (?x eGFR_Is ?z) ge(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 5.5) (?y rdf:type Usual_KCl_Dose) → (?x was_Suggested_to ?y)]
32	(?x rdf:type Patient) (?x has_Diabetes T2DM) (?x Control_DM_with_Insulin_Injection) (?x eGFR_Is ?z) ge(?z, 45) (?x Plasma_K_level_Is ?w) le(?w, 5.5) (?y rdf:type Usual_KCl_Dose) → (?x was_Suggested_to ?y)
33	(?x rdf:type Patient) (?x Water_Restrictions_is No_Water_Restrictions) (?y rdf:type Ordinary_Rate) → (?x was_Suggested_to ?y)
34	(?x rdf:type Patient) (?x Water_Restrictions_is Slight_Water_Restrictions) (?y rdf:type Slow_Rate) → (?x was_Suggested_to ?y)
35	(?x rdf:type Patient) (?x Water_Restrictions_is Strict_Water_Restrictions) (?y rdf:type Very_Slow_Rate) → (?x was_Suggested_to ?y)
DM, diabetes mellitus; eGFR, enhanced glomerular filtration rate; IV, intravenously; T1DM, type 1 diabetes mellitus; T2DM, type 2 diabetes mellitus.	

Appendix 3

Appendix Table A2. Survey of Ontology-Based Clinical Decision Support System for Diabetic Patients Undergoing Surgery

QUESTION, RESPONSE	SCORING				
	1	2	3	4	5
Do you think the system can provide some benefits for you?					
Using the system improves my performance in my job.	☐	☐	☐	☐	☐
Using the system enhances my effectiveness in my job.	☐	☐	☐	☐	☐
I find the system to be useful in my job.	☐	☐	☐	☐	☐
What do you think about this system? Are you satisfied with its accuracy?					
Is the system accurate?	☐	☐	☐	☐	☐
Are you satisfied with the results of the system?	☐	☐	☐	☐	☐
If this system is used in conjunction with the actual work, would you continue to use this system at work?					
I enjoy using this system at work.	☐	☐	☐	☐	☐
I will frequently use this system in the future.	☐	☐	☐	☐	☐
I will strongly recommend to others to use this system.	☐	☐	☐	☐	☐

Sex :

[illegible]

P.S.

GKI10 : Dext10% 500 mL + RI 10 units+ 10 meq KCl (at 100 mL/h)

- Additional Instructions:

Call Diabetes Team if CBG > ____mg/dL or CBG < ____mg/dL

```

graph TD
    Start[Capillary blood glucose (CBG) tests every 2 hrs; 1hr if unstable] --> CBG_Target[CBG target range]
    CBG_Target --> CBG_Low[CBG < 120]
    CBG_Target --> CBG_Mid[CBG 120-200]
    CBG_Target --> CBG_High[CBG > 200]
    
    CBG_Low --> IV_Fluid[IV fluid]
    CBG_Mid --> RI[RI]
    CBG_High --> KCl[KCl]
    
    IV_Fluid --> Infusion_Rate[Infusion rate]
    RI --> Infusion_Rate
    KCl --> Infusion_Rate
    
    Infusion_Rate --> End[Call Diabetes Team if IV fluids required for more than 24 hours or when due to restart oral intake]
    Infusion_Rate --> Start
  
```

Capillary blood glucose (CBG) tests every 2 hrs; 1hr if unstable

CBG target range

Default Value	CBG	CBG	CBG
	< 120	120 -200	> 200
Patient-Specific	< ()	()-()	>()

IV fluid

Default Value	GKI10	GKI15	GKI20
Patient-Specific			

RI

Default Value	RI 10Units	RI 15Units	RI 20Units
Patient-Specific	RI Units	RI Units	RI Units

KCl

Default Value	KCl 10 meq	KCl 10 meq	KCl 10 meq
Patient-Specific	KCl meq	KCl meq	KCl meq

Infusion rate

Default Value	100 cc/hr	100 cc/hr	100 cc/hr
Patient-Specific	cc/hr	cc/hr	cc/hr

POST-OP

Call Diabetes Team if IV fluids required for more than 24 hours or when due to restart oral intake

POST-OP

Appendix Fig. A2. Flowchart II. CBG, capillary blood glucose; Dext, dextrose; IV, intravenous; RI, regular insulin.

Name:	Serum Na ⁺ (mEq/L)	Date	Serum K ⁺ (mEq/L)	Date	Serum Cr (mEq/L)	Date	Fasting blood glucose (mg/dl)	Date
Age: Sex:								
Hospital No.:	HbA1c	Date	Height		Weight		Capillary blood glucose (CBG)	
Operation (op)								
Time of op								
Anesthesia	☐ Generalized ☐ Spinal ☐ Local							
Present	OAD							
Anti-diabetic	Insulin							
medications								

Appendix Fig. A3. The clinical profile needed before the operation. CBG, capillary blood glucose; Cr, creatinine; HbA1c, hemoglobin A1c; OAD, oral antidiabetes drug; op, operation.