Clinical decision support (CDS) and Arden Syntax

Educational material, part 1

Medexter Healthcare
Borschkegasse 7/5
A-1090 Vienna

www.medexter.com

www.meduniwien.ac.at/kpa (academic)

Better care, patient safety, and quality assurance by Medexter, Vienna, Austria
Clinical decision support
Towards clinical decision support

Steps of natural progression

• patient administration
  – admission, transfer, discharge, and billing

• documentation of patients’ medical data
  – electronic health record: all media, distributed, life-long (partially fulfilled)

• patient and hospital analytics
  – data warehouses, quality measures, reporting and research databases, data and text mining, patient study recruitment
    … population-specific

• clinical decision support
  – safety net, quality assurance, evidence-based
    … patient-specific
Digitalization in medicine

- Healthcare systems
- Patient data
- Medical data
- Patient care
- Images, signals
- Systems biology
- Molecular medicine

---

Macro:
- National and transnational eHealth
- HIS, EHRs, interoperability
- EMRs, data models, ontologies
- CDS, AI, expert systems, NLP
- Imaging and visualization
- Modelling and simulation
- Bioinformatics
Digitalization in clinical medicine

- **Stage I: Digitizing medical patient data**
  - EHRs, EMRs, Health Apps, images, bio-signals, national, ...

- **Stage II: Digitizing clinical workflows**
  - In-patient care, wards, departments, out-patient, home, chronic care, ...

- **Stage III: Digitizing medical knowledge**
  - Anatomy, physiology, pathophysiology, nosology, pharmacology, pharmacogenomics, ...

Clinical decision support—Applying knowledge to data

clinical demand

- Better care
- Patient safety
- Quality assurance
- Cost reduction
Clinical decision support: Infinite extent

Medical data
- national health systems
- EHR, EMR
- GP SW
- mobile health apps
- ...

Medical knowledge with processing engines
- alerts, reminders, recommendations, calculations, ...
- hepatitis serology, toxoplasmosis serology, ...
- rheumatology for GPs, ...
- rheumatology for clinics, ...
- HAI alerts, surveillance, reports, ...
- guidelines for diabetes, ...
- hepatitis at pregnancy, ...

Data systems + knowledge systems

Infinite content complexity

Infinite clinical subjects
Clinical medicine: high complexity

• **sources of medical knowledge**
  - factual/causal
  - definitional
  - statistical
  - heuristic

• **layers of medical knowledge**
  - observational and measurement level
  - interpretation, abstraction, aggregation, summation
  - pathophysiological states
  - diseases/diagnoses, therapies, prognoses, management decisions

• **imprecision, uncertainty, and incompleteness**
  - imprecision (=fuzziness) of medical concepts
    * due to the unsharpness of boundaries of linguistic concepts
  - uncertainty of medical conclusions
    * due to the uncertainty of the occurrence and co-occurrence of imprecise medical concepts
  - incompleteness of medical data and medical theory
    * due to only partially known data and partially known explanations for medical phenomena

• **“gigantic” amount of medical data and medical knowledge**
  - patient history, physical examination, laboratory test results, clinical findings
  - symptom-disease relationships, disease-therapy relationships, gene-drug relationships, ...
  - terminologies, ontologies: SNOMED CT, LOINC, UMLS, ...

specialization, teamwork, quality management, computer support ➔ CDS
Literature on “Clinical Decision Support”: 36,211 publications

Max Plischke, 2015
studies in Colorado and Utah and in New York (1997)
- errors in the delivery of health care leading to the death of as many as 98,000 US citizens annually

causes of errors
- error or delay in diagnosis
- failure to employ indicated tests
- use of outmoded tests or therapy
- failure to act on results of testing or monitoring
- error in the performance of a test, procedure, or operation
- error in administering the treatment
- error in the dose or method of using a drug
- avoidable delay in treatment or in responding to an abnormal test
- inappropriate (not indicated) care
- failure of communication
- equipment failure

prevention of errors
- we must systematically design safety into processes of care

Based on our estimate, medical error is the 3rd most common cause of death in the US.

- Cancer: 585k
- Medical error: 251k
- Heart disease: 611k
- COPD: 149k
- Suicide: 41k
- Motor vehicles: 34k
- Firearms: 34k

All causes: 2,597k

However, we’re not even counting this - medical error is not recorded on US death certificates.

Data source:
http://www.cdc.gov/nchs/data/nvsr/nvsr64/nvsr64_02.pdf

© 2016 BMJ Publishing group Ltd.
CLINICAL DECISION SUPPORT
The Road to Broad Adoption

Improving Outcomes with Clinical Decision Support
An Implementer’s Guide
Second Edition

Jerome A. Osheroff, MD, FACP, FACMI
Jonathan M. Talich, MD, PhD, FACMI, FHIMSS
Donald Levick, MD, MBA, FHIMSS
Luis Saldana, MD, MBA, FACEP
Ferdinand T. Velasco, MD
Dean F. Stett, PhD, FACMI, FHIMSS
Kendall M. Rogers, MD, CPE, FACP, SFHM
Robert A. Jenders, MD, MS, FACP, FACMI

HIMSS®

Second Edition

Edited by Robert A. Greenes
Clinical decision support: Definitions

- Foundational: Key origin of field of biomedical informatics
  - AIM = artificial intelligence in medicine
  - computer-based diagnosis in the heyday of AI

- Now: Intelligent assistant
  - support/assist human decision makers, not supplant them

⇒ Core: Applying knowledge to data

Approaches to CDS

- Medical publications
  - Abstracted texts
  - Display: Authoritarian
    - E.g., UpToDate by Wolters Kluwer

- "Big" imaging data
  - Pattern recognition
  - Annotation: Empirical, Low Level
    - E.g., Watson Health by IBM

- "Big" structured data
  - Data mining
  - Induction: Empirical, Low Level

- "Big" published texts
  - Text mining
  - Induction: Empirical, High Level

- Knowledge design
  - Deduction: Axiomatic
  - Knowledge-based systems

The diagram illustrates various approaches and methods used in Clinical Decision Support (CDS), focusing on data types, knowledge design, and delivery methods, with examples of tools and providers.
Knowledge design

based upon

individual “proprietary” knowledge

consensual “institutional” knowledge

designed knowledge for the digital age

written documents

multi-stakeholder Kaizen events

computerized medical knowledge

e.g.,

EHR alerts, MES, AppStore apps, SaaS apps, CDS Hooks, medical knowledge engines

Kai – change; Zen – (continuous) improvement
HAVANNA H, MD, Ann SF Lok, MD
Section Editors: Rafael Esteban, MD, Louise Wilkins-Haug, MD, PhD
Deputy Editor: Jennifer Mitty, MD, MPH

Contributor Disclosures

All topics are updated as new evidence becomes available and our peer review process is complete.


INTRODUCTION — Hepatitis B virus (HBV) infection during pregnancy presents with unique management issues for both the mother and the fetus. These include the effects of HBV on maternal and fetal health, the effects of pregnancy on the course of HBV infection, treatment of HBV during pregnancy, and prevention of mother-to-child transmission.

Prevention of mother-to-child transmission is an important component of global efforts to reduce the burden of chronic HBV since vertical transmission is responsible for approximately one-half of chronic infections worldwide. The risk of developing chronic HBV infection is inversely proportional to the age at time of exposure. The risk is as high as 96 percent in those exposed at birth without vaccination, while the risk is much lower (about 20 to 30 percent) in those exposed during childhood. Maternal screening programs and universal vaccination of infants have significantly reduced transmission rates.

This topic will review special considerations for the management of patients with acute and chronic HBV infection during pregnancy and the post-partum period, as well as prevention of mother-to-child transmission. Additional topic reviews that address prevention and management of HBV infection in children, and liver disease in pregnancy, are found elsewhere:

- (See “Hepatitis B virus immunization in infants, children, and adolescents”)
- (See “Hepatitis viruses and the newborn: Clinical manifestations and treatment”)
- (See “Overview of hepatitis B virus infection in children and adolescents”)
- (See “Acute fatty liver of pregnancy”)
- (See “HELLP syndrome”)
- (See “Intrahepatic cholestasis of pregnancy”)
- (See “Approach to liver disease occurring during pregnancy”)
- (See “Pregnancy in women with pre-existing chronic liver disease”)

ACUTE HEPATITIS B VIRUS INFECTION — Acute viral hepatitis is the most common cause of jaundice in pregnancy [1]. Other causes include liver diseases associated with pregnancy, such as acute fatty liver of pregnancy, HELLP syndrome, and intrahepatic cholestasis of pregnancy. (See “Approach to liver disease occurring during pregnancy” and “Acute fatty liver of pregnancy” and “HELLP syndrome” and “Intrahepatic cholestasis of pregnancy.”)

Acute hepatitis B virus (HBV) infection during pregnancy is usually mild and not associated with increased mortality or teratogenicity [1,2]. Thus, infection during gestation should not prompt consideration of termination of the pregnancy. However, there have been reports of an increased incidence of low birth weight and prematurity in infants born to mothers with acute HBV infection [2,3].

Acute HBV occurring early in the pregnancy has been associated with a 10 percent perinatal transmission rate [3]. Transmission rates significantly increase if acute infection occurs at or near the time of delivery, with rates as high as 60 percent reported [1]. Thus, serial monitoring should be performed throughout pregnancy and if the mother remains hepatitis B surface antigen (HBsAg)-positive at delivery, the infant should be given prophylaxis with hepatitis B immune globulin immediately after birth and hepatitis B vaccine within 12 hours [3].
Watson Health by IBM: “Big” data
Moni by Medexter for HAI surveillance: Knowledge design
Moni: Healthcare-associated infection surveillance at ICUs

* Septicemias
  - primary, secondary, device-associated, unknown origin

* ICU-acquired pneumonias
  - bronchitis, pneumonia, various degrees of mibi confirmation

* Urinary tract infections
  - mibi-confirmed, not mibi-confirmed

* Central-venous-catheter-related infections
  - local, global, no positive blood culture, mibi-confirmed
Clinical event monitoring at ICUs: Knowledge design

Patient, Anita
Sex: Female  NID: QR 13 62 56
Age: 51  Case Number: 406901
Date of Birth: 12/09/1965  Hospital Admission: 04/02/2016

ICU Events

04/04/2016
- Max. body temperature: 38.2°C
- Shock index: 1.26
- Blood pressure syst.: ...
- Blood pressure dia.: ...

04/05/2016
- Max. body temperature: 38.4°C
- Shock index: 1.26
- Blood pressure syst.: ...
- Blood pressure dia.: ...

04/02/2016
- Max. body temperature: 37.8°C
- Shock index: 0.72
- Blood pressure syst.: ...
- Blood pressure dia.: ...

Hematological Profile
- Leukocytes [mL]: 4.91
- C-reactive protein [mg/l]: 178.6
- Ventilated: yes  yes  yes
- Adapted Murray score difference: 0 3 3

ICU Events

04/04/2016
- Max. body temperature: 38.2°C
- Shock index: 1.26
- Blood pressure syst.: ...
- Blood pressure dia.: ...

04/05/2016
- Max. body temperature: 38.4°C
- Shock index: 1.26
- Blood pressure syst.: ...
- Blood pressure dia.: ...

04/02/2016
- Max. body temperature: 37.8°C
- Shock index: 0.72
- Blood pressure syst.: ...
- Blood pressure dia.: ...
IBM Watson Health and Medexter Health Knowledge

Raw data

Machine learning

Document data

Cognitive engine

Implicit knowledge

Based on associations
Empirical cases
Partially transparent

Knowledge engine

Explicit knowledge

Based on relationships
Common, rare, and "impossible" cases
Fully transparent

Structured knowledge
Causal knowledge
Machine learning results

Knowledge design

Processing engine
Prediction: Medical knowledge engines

*Medical knowledge engines will improve health outcomes and quality of life for millions of people.*

A 60-year history:

+ Computer-assisted diagnosis and therapy (statistical, probabilistic, and logical models)
+ Medical expert systems (heuristic approaches)
+ Early AI in medicine (consultation systems)

+ Now: CDS (reasoning) and again AI in medicine (NLP, machine learning)
Medical Knowledge Engines

Use it as part of your EMR or as stand-alone application.

Medical Knowledge
- medical logic modules

CDS Engine

The prediction:
In the future, any clinical activity will be either supported or substituted by Medical Knowledge Engines.

The medical knowledge
- clinically proven knowledge: rules, tables, decision trees, guidelines, scores, algorithms, ...
- evidence-based, application-ready knowledge packages
- knowledge design or knowledge through machine learning

The CDS engine
- HL7’s Arden Syntax medical knowledge representation and processing, with fuzzy methodologies
- scalable from cloud-based services to mobile apps
Clinical decision support with knowledge engines

**DIAGNOSIS**
- alerts, reminders, to-do lists
- clinical test interpretations and temporal abstraction
- (tele)monitoring of chronic conditions
- differential diagnostics
  - rare diseases, rare syndromes
  - further diagnostic procedures
  - multi-morbidity
- genetics, proteomics
  - molecular variations

**PROGNOSIS**
- illness severity scores, prediction rules
- trend detection and visualization

**THERAPY**
- drug alerts, reminders, calculations
  - indication, contraindications, redundant medications, cost-effective substitutions
  - dosage calculations, drug-drug and gene-drug interactions
  - adverse drug events
- management of antimicrobial therapies
  - susceptibility and resistance rates
- pharmacogenomics

**HOSPITAL MANAGEMENT**
- computerized evidence-based workflows, clinical guidelines, protocols, SOPs
- surveillance criteria and quality benchmarking

**Knowledge Engines**
Arden Syntax
Arden Syntax: HL7- and ANSI-approved

- An **HL7 standard language** for writing situation-action rules, procedures, or knowledge bases that trigger results based on clinical events detected in patient data

- Each module, referred to as a medical logic module (MLM), contains sufficient knowledge to make at least a single medical decision
  - extended by medical knowledge packages (MKPs) consisting of interconnected MLMs for complex clinical decision support

- **Continuous development**
  - The Health Level Seven Arden Syntax for Medical Logic Systems, **version 2.9—including fuzzy methodologies**—was approved by Health Level Seven (HL7) International and the American National Standards Institute (ANSI) in 2013.
  - The latest version, **Version 2.10—including ArdenML, an XML-based representation of Arden Syntax MLMs**—was approved in 2014.

⇒ healthcare industry and academic users
History

- 1989: A first draft of the standard was prepared at a meeting at the Arden Homestead, New York. Arden Syntax was subsequently adopted as a standard by the American Society for Testing and Materials (ASTM) as document E 1460, under subcommittee E 31.15 Health Knowledge Representation.

- 1992: Arden Syntax version 1.0

- 1998: sponsorship moved to HL7 International (Arden Syntax Work Group)

- 1999: Arden Syntax version 2.0 approved by HL7 and the American National Standards Institute (ANSI)

- 2013: Fuzzy Arden Syntax (Arden Syntax version 2.9)

- 2014: Arden Syntax version 2.10

- Continuous development
<table>
<thead>
<tr>
<th>Version</th>
<th>Year</th>
<th>Important changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>2002</td>
<td>new string operators; reserved word “currenttime” returns the system time</td>
</tr>
<tr>
<td>2.5</td>
<td>2005</td>
<td>object capabilities: create and edit objects; XML representation of MLMs (except logic, action and data slot)</td>
</tr>
<tr>
<td>2.6</td>
<td>2007</td>
<td>UNICODE encoding; additional resources category to define text resources for specific languages; time-of-day and day-of-week data types; “localized” operator to access texts in specific languages</td>
</tr>
<tr>
<td>2.7</td>
<td>2008</td>
<td>enhanced assignment statement; extended “new” operator to allow easy and flexible object instantiation</td>
</tr>
<tr>
<td>2.8</td>
<td>2012</td>
<td>additional operators for list manipulation; operators to manipulate parts of given date and time values; switch statements; keyword “breakloop” for aborting a loop; number of editorial corrections</td>
</tr>
<tr>
<td>2.9</td>
<td>2013</td>
<td><strong>Fuzzy</strong>: fuzzy data types, fuzzy sets, and fuzzy logic; adjustment of all available operators to be able to handle fuzzy data types</td>
</tr>
<tr>
<td>2.10</td>
<td>2014</td>
<td>XML representation of MLMs (including logic, action and data slot)</td>
</tr>
</tbody>
</table>
What is Arden Syntax?

• ... a knowledge representation standard primarily meant for medical knowledge.

• ... used for sharing computerized health knowledge bases across personnel, information systems, and institutions.

• ... organized in modules. Each module is referred to as a medical logic module (MLM) and contains sufficient knowledge to make at least a single medical decision.

• ... a computer-interpretable format that is used by clinical decision support systems.