Healthcare-associated infection prevention and control: IT-based quality assurance and clinical decision support

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www.meduniwien.ac.at/kpa
What is the challenge?

- increase in susceptibility to infections
  - modern medicine saves lives
- increase in antibiotic resistance
  - e.g., MRSA
- demand for benchmarking and quality assurance
  - surveillance and reporting

⇒ (1) hand hygiene
  (2) information technology
ESBL – extended-spectrum beta-lactamase-producing bacteria

VRE - vancomycin-resistant enterococcus

MDR-TB - multidrug-resistant tuberculosis

increased disposition by low immunity

exposure to pathogens

ESBL - extended-spectrum beta-lactamase-producing bacteria

VRE - vancomycin-resistant enterococcus

MRSA - methicillin-resistant Staphylococcus aureus

MDR-TB - multidrug-resistant tuberculosis

MRSA - methicillin-resistant Staphylococcus aureus

entry sites
Information technology in infection prevention and control

- Supporting tools for
  - analytics
  - surveillance
  - benchmarking
  - monitoring
  - alerting
  - reporting

⇒ Providing a variety of supportive tasks with different population- and patient-specific, procedure- and rule-based algorithms

⇒ Fully automated primary data acquisition through EMRs strongly recommended
Momo

- analysis of microbial isolates and antimicrobial resistance (AMR) patterns with multi-dimensional table statistics

and

- monitoring of
  - cross transmissions
  - frequencies and trends for selected microbes and AMR patterns
Questions that can typically be answered are:
- Welche Erreger sind zurzeit in meinem Krankenhaus im Umlauf und welcher Patient ist betroffen?
- Welche Antibiotikaresistenzen weisen diese auf?
- Welche Erreger sind multiresistent?
- Wie viel resistente und multiresistente Erreger sind aufgetreten, z.B. Methicillin-resistente Staphylokokken aureus (MRSA), Vancomycin-resistente Enterokokken (VRE) und multiresistente Gram-Negative gegen 2, 3, oder 4 Antibiotikaklassen (2, 3, 4 MRGN)
- Gibt es meldepflichtige Erreger (EU->TESSy; National->AURES)?
- Wie ist die Verteilung von Resistenzien im Krankenhaus?
- Wie ist die Resistenzlage auf den einzelnen Abteilungen im Krankenhaus?
Composition of query and filtering of inputs (repeat isolates, attribution of intermediate resistance, ... )
Tabulation of results

- Crosstables (microbe species and/or specimen vs. antimicrobials)
- Reports on MRSA, ESBL, VRE, ...
- Report for AURES
- Report for TESSy
Automated HAI surveillance with MONI

Intelligent, knowledge-based software able to extract and analyze HAI-related information from structured clinical and laboratory data held in PDMSs and LISs

**MONI-ICU and MONI-NICU**

HAI monitoring (surveillance as well as alerts) in ICUs for adult and neonatal patients, resp.

**Characteristics**

1. Fully automated and prompt acquisition of structured medical data from PDMSs and LISs
2. Medical knowledge bases contain computerized knowledge of all relevant clinical entities (e.g., ECDC HAI definitions, definitions for clinical alerts, ...)
3. Processing algorithms evaluate, aggregate, and interpret stepwise until clinical raw data can be mapped into the given definitions
### Krankenblatt (Neo)

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**Auto-Dokumentation alle 15 Min.**

**Grafik**

**Vitalparameter**

**Medikamente**

**Perfusoren**

**Einfuhr**

**Ausfuhr**

**Bilanz**

**Kathy/Drains**

**GI**

**CAPD**

**Pflege**

**N-PASS**

**Neuro**

**Labor**

**Stat.**

**Further Information**

- **Medikamente**
- **Perfusoren**
- **Einfuhr**
- **Ausfuhr**
- **Bilanz**
- **Kathy/Drains**
- **GI**
- **CAPD**
- **Pflege**
- **N-PASS**
- **Neuro**
- **Labor**
- **Stat.**
ICU, NICU, and microbiology patient data bases

layer 0 (start)

layer 1
preprocessing:
missing data, plausibility, ...

layer 2
feature extraction:
mean values, scores, ...

layer n-x-y-1
abstraction:ules, type-1 & type-2 fuzzy sets, temporal abstraction

layer n-x-y
basic concepts:
symptoms, signs, test results, clinical findings

layer n-y
intermediate concepts:
pathophysiological states

layer n (goal)
linguistic HAI definitions

patient-specific cockpit
& legal reporting
& quality benchmarking

raw data

data-to-symbol conversion

symbols

reasoning

…
Surveillance cockpit

Colors indicate patient days with infection and % fuzziness degree of compatibility with case definitions for HAI

Each line represents a single patient stay

One patient stay selected

One day extended and line listed

Elements in rule tree and % fuzzy degree of compatibility for each

Underlying clinical and lab findings
Moni output

Section of Moni screenshot for one ICU: Colors indicate patients with infection episodes
Arden Syntax: HL7- and ANSI-approved

- A standard language for writing situation-action rules, procedures, or knowledge bases that compute results based on clinical events detected in patient data
  - continuous development since 1989
- Each module, referred to as a medical logic module (MLM), contains sufficient knowledge to make a single decision
- Medical knowledge packages (MKPs) consist of interconnected MLMs for complex clinical decision support
- 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
- Version 2.10—including ArdenML, an XML-based representation of Arden Syntax MLMs—was approved in 2014

⇒ healthcare industry and academic users
General MLM Layout
Maintenance Category
Library Category
Knowledge Category
Resources Category

Identify an MLM

Data Types

Operators
Basic Operators
Curly Braces
List Operators
Logical Operators
Comparison Operators
String Operators
Arithmetic Operators
Other Operators

Control Statements

Call/Write Statements and Trigger
Translation of HAI definitions into IT terminology—example: bloodstream infections (BSIs)

HELICS-protocol HAI in ICU, version 6.1, Sep. 2004

**CODE:** BSI

**BSI-A:**
- 1 positive blood culture for a **recognized pathogen**
- or
- Patient has at least one of the following signs or symptoms: fever (>38°C), chills, or hypotension and 2 positive blood cultures for a common skin contaminant (from 2 separate blood samples drawn within 48 hours).

Skin contaminants = coagulase-negative staphylococci, Micrococcus sp., Propionibacterium acnes, Bacillus sp., Corynebacterium sp.

**BSI-B:** Patient has at least one of the following signs or symptoms: fever (>38°C), chills, or hypotension

And either:
- 1 positive blood culture with a skin contaminant in patient with an intravascular line in place and in whom the physician instituted appropriate antimicrobial therapy.
- or
- positive blood Antigen test (e.g. H.influenzae, S.pneumoniae, N. meningitidis or Group B Streptococcus)

**Comment:**
BSI-A is the definition used by the majority of NI surveillance networks in Europe. BSI-B extends this definition to the CDC definition of laboratory-confirmed bloodstream infection. Networks should specify in the network data (table icu_net, see 6.3.1) whether only BSI A or both BSI B and BSI A are included in the surveillance (i.e. networks using CDC definition of laboratory confirmed bloodstream infection [CDC_CLINICALINFECTIONDISEASE_A06]). If this is the case, then BSI A and BSI B categories should be specified in the data collection.

**IT statement in free language**

**Recognized pathogen**

OR clinical signs AND growth of same skin contaminant from two separate blood samples

**OR clinical signs AND growth of same skin contaminant from blood AND intravascular line**

**OR clinical signs AND positive antigen test from blood**
A bloodstream infection—with clinical signs and growth of same skin contaminant from two separate blood samples

- Patient has at least one of the following signs or symptoms: fever (>38°C.), chills, or hypotension and 2 positive blood cultures for a common skin contaminant (from 2 separate blood samples drawn within 48 hours).

  skin contaminants = coagulase-negative staphylococci, Micrococcus sp., Propionibacterium acnes, Bacillus sp., Corynebacterium sp.

BSI-A2

\[
1 \iff \text{clinical Signs of BSI (t-1d, t, t+1d)} \land \text{same skin contaminant from two separate blood samples}
\]
Decomposition—clinical signs

clinical_signs_of_BSI (t-1d, t, t+1d) [yesterday, today, tomorrow]

= feverT (t-1d) ∨ hypotension (t-1d) ∨ clinical_signs_of_BSI (t-1d) = leucopenia (t-1d) ∨ leucocytosis (t-1d) ∨ CRP increased (t-1d)

∨

clinical_signs_of_BSI (t) = feverT (t) ∨ hypotension (t) ∨ clinical_signs_of_BSI (t) = leucopenia (t) ∨ leucocytosis (t) ∨ CRP increased (t)

∨

clinical_signs_of_BSI (t+1d) = feverT (t+1d) ∨ hypotension (t+1d) ∨ clinical_signs_of_BSI (t+1d) = leucopenia (t+1d) ∨ leucocytosis (t+1d) ∨ CRP increased (t+1d)
Linguistic uncertainty defined by fuzzy sets—example: fever

feverT (t-1d) ⇐ ...

feverT (t) ⇐ \{ fever
thermoregulation applied ...

feverT (t+1d) ⇐ ...
Decomposition—skin contaminant

first blood culture
- coagulase-negative staphylococci
- Micrococcus sp.
- Propionibacterium acnes
- Bacillus sp.
- Corynebacterium sp.

second blood culture
- coagulase-negative staphylococci
- Micrococcus sp.
- Propionibacterium acnes
- Bacillus sp.
- Corynebacterium sp.

\[ \text{same skin contaminant from two separate blood samples} \iff \text{(within 48 hours)} \]

\[ \text{data import microbiology} \]
Fuzzy Arden Syntax: Modeling uncertainty in medicine

- **linguistic uncertainty**
  - due to the unsharpness (fuzziness) of boundaries of linguistic concepts; gradual transition from one concept to another
  - modeled by fuzzy sets (e.g., fever, increased glucose level, hypoxemia)

- **propositional uncertainty**
  - due to the incompleteness of medical conclusions; uncertainty in definitional, causal, statistical, and heuristic relationships
  - here: modeled by truth values between zero and one (e.g., 0.6, 0.9)
Examples of fuzzy sets as they are applied in Moni-ICU

- Leukopenia: 4,000 - 5,000 WBC/mm³
- Leukocytosis: 11,000 - 12,000 WBC/mm³
- Fever: 37.5 - 38.0°C
- Shock Index: Systolic Blood Pressure / Heart Rate

DoC (Degree of Confidence) values are shown for each condition, indicating the degree to which the condition is present.
Two different hyperglycemia definitions

Hyperglycemia (surveillance) is true is 1.00. Hyperglycemia (alerting) is true is 0.75.
Clinical concepts and relationships between them

\[ (S_1 \land S_2) \lor \neg S_3 \rightarrow t \rightarrow D \]

truth value

degree of compatibility

DoC

1.0

0.8

0

fever

37.5  38.0  37.9

\( ^\circ C \)
Arden Syntax server and software components

- Arden Syntax integrated development and test environment (IDE) including
  - Medical logic module (MLM) editor and authoring tool
  - Arden Syntax compiler (syntax versions 2.1, 2.5, 2.6, 2.7, 2.8, 2.9, and 2.10)
  - Arden Syntax engine
  - MLM test environment
  - MLM export component
- command-line Arden Syntax compiler
- web-services-based Arden Syntax server including
  - Arden Syntax engine
  - MLM manager
  - XML-protocol-based interfaces, e.g., SOAP, REST, and HL7
  - a project-specific data and knowledge services center
- Java libraries
  - Arden Syntax compiler
  - Arden Syntax engine

Data warehouse & knowledge server
- selected data and results, e.g., ICU&NICU and Moni, microbiology
- reporting, quality measures and benchmarking
- study support and recruitment
- App docking station (e.g., FHIR)
- data and knowledge mining (big data)
Questions that can typically be answered are:

- Wie viele und welche Patienten in meinem Krankenhaus auf welchen Stationen und zu welchem Grad weisen Merkmale nosokomialer Infektionen auf?
- Wie hoch ist die Prävalenz und Inzidenz der Infektionen?
- Wie viele und welche Patienten weisen Infektionen auf, die unter Surveillance stehen?
- Wie hoch ist die Rate der katheter-assoziierten Harnwegsinfektionen (CAUTIs), ventilations-assozierten Pneumonien (VAPs) und anderer nosokomialer Infektionen?
- Wie hoch ist die Katheteranwendungsrate, Beatmungsrate, ...?
- Welche Stationen sind im Vergleich zu anderen Stationen häufiger von Infektionen betroffen (Hygienemaßnahmen notwendig)?
- Erfolgt eine Übertragung von Resistenzen auf andere Patienten?
- Welche Patienten entwickeln gerade erste Anzeichen einer nosokomialen Infektion und sollten daher diesbezüglich engmaschiger überwacht werden?
Standard surveillance report
(10 ICUs, one month)

**Denominator data**
*(table)*

- admissions
- patient days
- mean length of stay (days)
Standard surveillance report
(10 ICUs, one month)

**Device use**

- urine catheter days

- central venous catheter days

- respirator days
Standard surveillance report
(10 ICUs, one month)

HAI\textsuperscript{s} by syndrome and type,
here:

\textbf{Catheter-related infection CRI}

Frequencies CRIs by type

central-venous-catheter (CVC)-
associated CRI rates
(n/1000 device days)
Protokoll

Surveillance nosokomialer Infektionen und multiresistenter Erreger auf Intensivstationen

© Nationales Referenzzentrum für Surveillance von nosokomialen Infektionen
am Institut für Hygiene und Umweltmedizin
Charité - Universitätsmedizin Berlin

Internet: http://www.nrz-hygiene.de

Stand: Dezember 2010

Protokoll

Surveillance nosokomialer Infektionen bei Frühgeborenen mit einem Geburtsgewicht < 1.500g

© Nationales Referenzzentrum für Surveillance von nosokomialen Infektionen
am Institut für Hygiene und Umweltmedizin
Charité - Universitätsmedizin Berlin

Internet: http://www.nrz-hygiene.de

Stand: 22. Dezember 2009
Patientenbogen zur Surveillance – NEO-KISS

Infektionsbogen Pneumonie – NEO-KISS

Infektionsbogen NEC – NEO-KISS

Infektionsbogen Sepsis – NEO-KISS
First study

⇒ 99 ICU patient admissions; 1007 patient days

HAI episodes correctly / falsely identified or missed by Moni-ICU

<table>
<thead>
<tr>
<th></th>
<th>episode present “gold standard” (n = 19)</th>
<th>episode absent “gold standard” (n = 78)</th>
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</thead>
<tbody>
<tr>
<td>episode present “Moni-ICU”</td>
<td>16 (84%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>episode absent “Moni-ICU”</td>
<td>3 (16%)</td>
<td>78 (100%)</td>
</tr>
</tbody>
</table>

Time expenditure for both surveillance techniques

<table>
<thead>
<tr>
<th></th>
<th>conventional surveillance</th>
<th>Moni-ICU surveillance</th>
</tr>
</thead>
<tbody>
<tr>
<td>time spent</td>
<td>82.5 h (100%)</td>
<td>12.5 h (15.2%)</td>
</tr>
</tbody>
</table>

Second study

⇒ 93 ICU patient admissions; 882 patient days; 30 HAI episodes over complete or partial duration of stay; 76 stays with no HAI episodes

HAI episodes correctly / falsely identified or missed by Moni-ICU

<table>
<thead>
<tr>
<th></th>
<th>gold standard</th>
<th>Moni-ICU</th>
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<tr>
<td>I+</td>
<td>26</td>
<td>26</td>
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<tr>
<td>I-</td>
<td>75</td>
<td>4</td>
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sensitivity = 87%
- 3 false-negative pneumonias + 1 false-negative CVC-related infection due to missing microbiology

specificity = 99%
- 1 false-positive CVC-related infection because of a present concomitant leukemia (with leukocytosis)

### Four clinical concepts in Moni-ICU

<table>
<thead>
<tr>
<th>Clinical Concept (Unit)</th>
<th>Fuzzy Set</th>
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<tbody>
<tr>
<td></td>
<td>Normal Range</td>
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<tr>
<td>Increased body temperature (fever) (°C)</td>
<td>&lt; 37.5</td>
</tr>
<tr>
<td>Increased C-reactive protein (CRP) (mg/dl)</td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>Leukopenia (WBC/mm³)</td>
<td>&gt; 5,000</td>
</tr>
<tr>
<td>Leukocytosis (WBC/mm³)</td>
<td>&lt; 11,000</td>
</tr>
</tbody>
</table>

1) as defined by clinicians  
2) as defined by CDC/NHSN, ECDC, and KISS for retrospective surveillance purposes  
3) as defined by clinicians; CRP is an early phase protein, useful as an “infection radar” for prospective purposes  
4) as defined by clinicians; white blood cell count (WBC) is a slowly reacting indicator, important for surveillance purposes
Frequency distributions: four clinical concepts as well as the topmost HAI definitions (24,325 patient days)

<table>
<thead>
<tr>
<th>Clinical Concept</th>
<th>Absent n (%)</th>
<th>Borderline n (%)</th>
<th>Present n (%)</th>
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<tbody>
<tr>
<td>Increased body temperature (fever)</td>
<td>16,074 (66.1)</td>
<td>3,421 (14.0)</td>
<td>4,830 (19.9)</td>
</tr>
<tr>
<td>Increased C-reactive protein (CRP)</td>
<td>4,383 (18.0)</td>
<td>5,841 (24.0)</td>
<td>14,101 (58.0)</td>
</tr>
<tr>
<td>Leukopenia</td>
<td>22,991 (94.5)</td>
<td>668 (2.8)</td>
<td>666 (2.7)</td>
</tr>
<tr>
<td>Leukocytosis</td>
<td>15,169 (62.4)</td>
<td>1,544 (6.3)</td>
<td>7,612 (31.3)</td>
</tr>
<tr>
<td>BSI or(^1) CRI2 or UTI-A or UTI-B</td>
<td>20,687 (85.0)</td>
<td>606 (2.5)</td>
<td>3,032 (12.5)</td>
</tr>
</tbody>
</table>

\(^1\) inclusive disjunction with precedence of “present” over “borderline” over “absent”
Significance of nosocomial infections

- 3 to 14% of patients admitted to acute care hospitals acquire one or more nosocomial infections
- in consequence, 5 to 7% of them die

**Vienna General Hospital with 2,200 beds:**

- patients admitted to wards: 94,715
- days of care: 688,619
- average length of stay: 6.1 days
- costs / patient / day: EUR 678.-

- nosocomial infections: 4,262 patients / year (rate of 4.5% assumed)
- 213 out of them die / year (5% mortality assumed)
- additional costs of EUR 14,448,180.- (5 days of prolonged stay, in average)

source: Prof. Dr. med. Ojan Assadian, Division of Hospital Hygiene, Medical University of Vienna (2002)
Combined reasons for Moni’s success

- clinical
  - no diagnoses, but graded compliance with definitions
  - no need for additional data entry
  - high-level monitoring cockpit
  - two-step reporting: (1) automated generation and (2) expert verification

- methodological
  - pure knowledge-based system with explanatory component
  - consensual surveillance criteria
  - hierarchical layers of data and knowledge
  - fuzzy set theory and logic

- technical
  - separation of PDMS data collection, microbiology data collection, service-oriented rule engine server, knowledge packages, and web-based infection control cockpit
  - integration of different hospital IT systems (PDMS, LIS, CDSS server)

- administrative
  - uniform digitized PDMS data sources at the connected ICUs and data from microbiology
  - support from medical administration
  - several lead users
### MONI-ICU: surveillance of healthcare-associated infections

#### Stat. 39690

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#### BSI-4 (primary diagnosis)

- **PNA (bact. indication of pneumococcal)**
  - 100 % DOC
  - 100 % NDC

#### Others

- Inflamm. symptoms in UTI
- Inflamm. symptoms in sepsis
- Fever
- Hypothermia
- High CRP
- Leucocytosis
- Blood pressure falling
- Shock
- High body temperature
- Max. body temperature
- Fraction of leukocytes
- Systemic antibiotics
- Pos. blood culture

**2013-05-23 (Stat. 39690)**

- 100 % DOC
- 100 % NDC

**2013-05-24 (Stat. 39690)**

- 100 % DOC
- 100 % NDC
Moni-NICU: (surveillance of and) alerts for healthcare-associated infections