*eHealth2014 – Health Informatics Meets eHealth*
*A. Hörbst et al. (Eds.)*


*doi:10.3233/978-1-61499-397-1-71*

# Healthcare-Associated Infection Surveillance and Bedside Alerts

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**Abstract.** Expectations and requirements concerning the identification and surveillance of healthcare-associated infections (HAIs) are increasing, calling for differentiated automated approaches. In an attempt to bridge the "definition swamp" of these infections and serve the needs of different users, we improved the monitoring of nosocomial infections (MONI) software to create better surveillance reports according to consented national and international definitions, as well as produce infection overviews on complex clinical matters including alerts for the clinician's ward and bedside work. MONI contains and processes surveillance definitions for intensive-care-unit-acquired infections from the European Centre for Disease Prevention and Control, Sweden, as well as the Centers for Disease Control and Prevention, USA. The latest release of MONI also includes KISS criteria of the German National Reference Center for Surveillance of Nosocomial Infections. In addition to these "classic" surveillance criteria, clinical alert criteria—which are similar but not identical to the surveillance criteria—were established together with intensivists. This is an important step to support both infection control and clinical personnel; and—last but not least—to foster co-evolution of the two groups of definitions: surveillance and alerts.

**Keywords.** Healthcare-associated infections, infection control, intensive care unit, surveillance, alerts, quality benchmarking, early detection.

## 1. Introduction

Intelligent information technology (IT) may serve as a meaningful tool in healthcare-associated infection (HAI) surveillance. As we showed at Medinfo 2010 in Cape Town [1], South Africa, and in subsequent studies [2, 3], the MONI surveillance tools developed for the Medical University of Vienna (MUV) / Vienna General Hospital (VGH), Austria, are associated with high sensitivity (69% to 96%) and high specificity (93% to 100%) in identifying intensive care patients who fulfill HAI surveillance

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criteria, and also reduce expert time spent in collecting relevant clinical, laboratory, and administrative surveillance data (less than one-sixth of manual surveillance). Since then, improvements and new features have been added to MONI. These enhance its sensitivity and specificity, especially for the assessment of ventilator-associated pneumonia (which was previously a diagnostic conundrum [4]). Additionally, the MONI alert functionality has been specially adapted to the bedside demands of clinicians. Thus, the scope of MONI is expanding from mere surveillance tasks to alert functions for clinical decision support (CDS). As shown in the work described here, surveillance and alert criteria differ from each other, but can be presented simultaneously to infection control and clinical personnel.

In doing so, we also address needs specified by others who have designed surveillance systems [4–7].

Historically, HAI surveillance started with the reporting of epidemiological data collected according to consented epidemiological definitions. In the meantime, HAI surveillance has become indispensable not only for quality management (QM) and patient safety, but also for hospital budgeting, public reporting and, last but not least, legal reasons. Thus, the quantity of data to be collected and analyzed, as well as the burden of such documentation for caregivers, has multiplied. Rather than collecting data for epidemiological reporting, doctors and nurses expect hospital infection control teams to assist them in their daily bedside work and in providing patients with the best possible care. However, viewing the same entity from different angles may aggravate the confusion of surveillance definitions. The demands on, and expectations of, infection surveillance and bedside alerts, as well as the strengths and weaknesses of the different approaches are listed in Table 1.

With our work, we attempted to establish intelligent IT tools that will fulfill the needs of epidemiologists and clinicians, supporting the co-evolution of both sides, and—as a corollary—develop greater mutual understanding and cooperation.

This paper describes the successful integration and processing of different surveillance and alert criteria for HAIs. A clinical evaluation of the incorporated alert criteria is not part of this report, but is one of the future steps. Medical device

**Table 1.** Expectations and requirements: epidemiological surveillance definitions versus clinically meaningful alert criteria

| | **HAI surveillance for epidemiology, benchmarking, and reporting** | **HAI detection for bedside alert, internal QM, and CDS** |
|---|---|---|
| Demands | Definitions must be stable over time to render results comparable over successive time periods; definitions must meet the demands of many institutions. | Definitions must reflect the state-of-the-art and must be clinically meaningful; results should support clinical bedside work, especially in complex situations (overviews, alerts, reminders). |
| Strengths | Mainly unambiguous criteria or definitions; expert consensus | Accepted by clinicians, provided the IT output reflects the clinician's perception of what is relevant and supportive for bedside work; prospective focus. |
| Weaknesses | Time-consuming consensus process; sub-optimal definitions resulting from the inaccessibility of relevant parameters; the criteria tend to lose pace with new developments in medicine; retrospective focus. | Often not discriminative enough to meet consented HAI definitions; may change quickly; rapid shifts foster ambiguity and discussions on their meaning with respect to consented surveillance definitions. |

regulations differ for surveillance and alerts. A brief discussion is provided. Differences between surveillance and alert criteria in terms of definition, especially in respect of their inherent linguistic uncertainty, are also discussed.

## 2. Methods

### *2.1. Site of Operation*

MONI is installed at the MUV/VGH, a tertiary teaching hospital comprising about 2,100 beds, and is connected to 14 intensive care units (ICUs). Ten ICUs comprise 87 beds for adults, while four accommodate a total of 46 beds for neonates.

### *2.2. Data Sources and Data Warehouse*

Structured denominator and medical data are downloaded daily into the database part of the MONI system. They are provided by Philips CareVue with a recent switch to ICCA, the new Philips patient data management system for ICUs, by the laboratory information system MOLIS by vision4health for clinical pathology and microbiology data, and further by the hospital IT system i.s.h.med by Siemens. The database part of MONI consists of a medical data warehouse with patients' administrative and raw medical data, and knowledge bases with computerized clinical knowledge on HAIs concerning all relevant clinical entities and their inter-relationships according to the given surveillance and alert definitions.

### *2.3. Knowledge Processing*

Processing algorithms [8, 9] evaluate, aggregate, and interpret raw medical data (measured test results, entered clinical signs) in a stepwise manner until these data—inferred by the established inference network—can be mapped into the given HAI surveillance and alert definitions. Most of the encoded clinical entities are modeled as fuzzy sets. Fuzzy logic is used to perform the subsequent inference steps. Clinical informaticians and experienced clinicians worked closely in carrying out the knowledge acquisition steps, such as the selection of clinical entities, the definition of fuzzy sets, the structuring, formalization, and incorporation of clinical knowledge, and the selection of operators (in fuzzy logic, you sometimes have a choice).

The surveillance definitions used here were derived from those published by the European Centre of Disease Prevention and Control (ECDC) [10], Stockholm, Sweden, and the Centers for Disease Control and Prevention, National Healthcare Safety Network (CDC/NHSN) [11], Atlanta, USA. In addition to these definitions, the latest version of MONI also processes KISS criteria according to the recommendations of the German National Reference Center for Surveillance of Nosocomial Infections, Berlin, Germany. The infection entities taken into account are various forms of septicemia, ICU-acquired pneumonia, urinary tract infection, and central-venous-catheter-related infection in adult patients in the ICU (see ITS-KISS [12]), as well as septicemia and ICU-acquired pneumonia in neonates (see NEO-KISS [13]). For the latter, so-called alert criteria designed to serve the needs of clinicians were developed along with "classic" surveillance criteria.

### 2.4. Arden Syntax Server

The technical basis of MONI is an Arden Syntax server including an Arden-Syntax-based rule engine, connected to the above-mentioned data warehouse [14, 15]. Data import routines interface with the data-providing systems; the knowledge bases are hosted in the Arden Syntax server. Clinical knowledge is represented in Arden Syntax medical logic modules (MLMs). These basic units are used to formalize and represent clinical knowledge in Arden Syntax [16]. It should be noted that Arden Syntax is supported by Health Level Seven (HL7) International [17], a standardization organization for health data, communication, and knowledge, and was also approved by the American National Standards Institute (ANSI) [18].

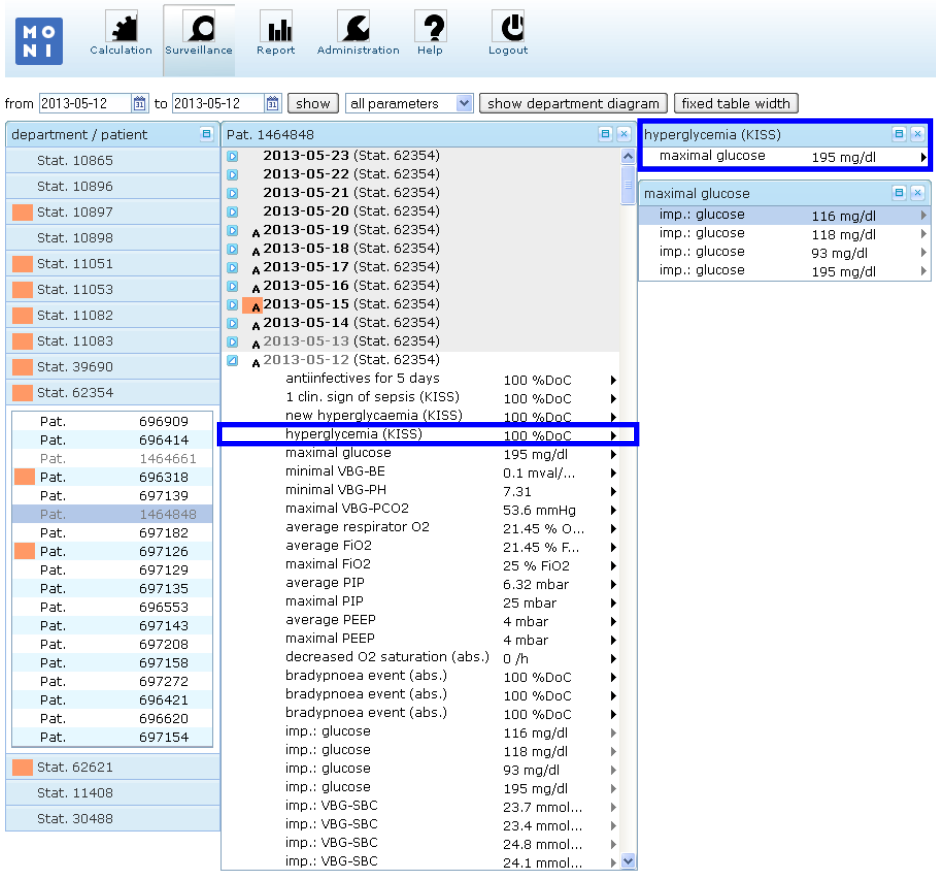


**Figure 1.** MONI-NICU cockpit view with NEO-KISS criteria (wards and patients were anonymized; wards and patients are listed on the left hand side of the screen. In the middle part, the number of days of the patient's NICU stay are shown with one day opened, final as well as intermediate, and some raw data are shown beneath the opened day). An explanation for one derived clinical concept—in this case hyperglycemia—is provided on the right side.

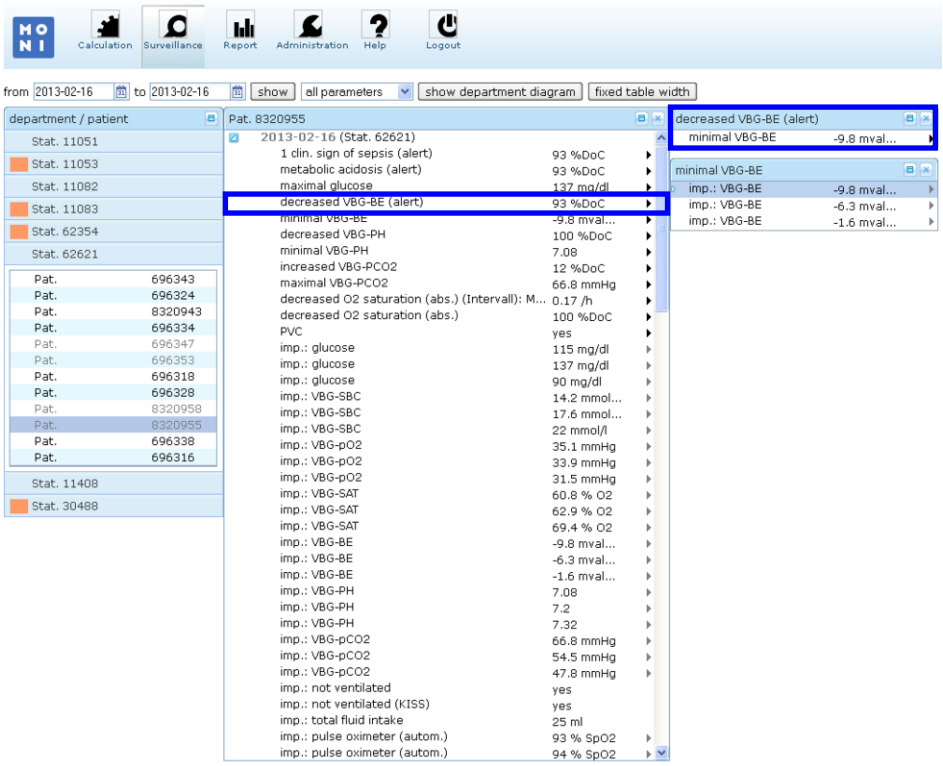


**Figure 2**. MONI-NICU cockpit view with fulfilled alert criteria on the opened day for the selected patient. An explanation for the derived clinical concept—decreased venous blood gas (VBG)—is provided on the upper right side.

## 3. Results

As shown in a screenshot from MONI's cockpit view in Figure 1, MONI provides—with a few mouse clicks—an overview of complex clinical issues on a single screen. (For details refer to the legend of Figure 1.) Please note that the examples presented here were derived from MONI applied to neonatal ICU patients; the system is known as MONI-NICU. At the present time, MONI comprises two knowledge bases: one for MONI-ICU and one for MONI-NICU.

With reference to the present discussion, the following situation is shown in Figure 1. As can be seen in the upper right corner of Figure 1, the clinical concept of hyperglycemia, which is part of a NEO-KISS surveillance definition, is fulfilled. The maximum glucose level of the day (12 May 2013) is 195 mg/dl. This is above the threshold for surveillance purpose (which is 140 mg/dl). Thus, the patient has the clinical condition of hyperglycemia in the context of surveillance. However, the value of 195 mg/dl is below the definition of hyperglycemia established for alert purpose; thus, hyperglycemia in the context of alerting is not present. It shall be noticed that hyperglycemia for alert purpose is defined by a fuzzy set with so-called degrees of compatibility (DoCs in Figures 1 and 2) [8, 19–21]. These degrees increase from zero to unity between 200 and 300 mg/dl in this case (see also Table 2), and indicate the

degree of compatibility between the measured value and the clinical concept under consideration. Zero (0%) means not compatible at all, unity (100%) stands for fully compatible, and a value between 0% and 100% expresses compatibility to a certain degree. Derived clinical concepts with a DoC smaller 10% are not listed in the cockpit view of MONI. The selected value of 10% is purely heuristic; its purpose is to avoid overload of presentation. Both, the surveillance and the alert definitions of hyperglycemia are shown in Figure 3.

Figure 2 depicts another interesting but similar clinical situation. Here the alert criterion for decreased venous blood gas (VBG) fired because the measured value was –9.8 mval/l and the fuzzy-based slope (fuzzified threshold) ranges from –7 to –10. The DoC for the measured value of –9.8 mval/l with the clinical concept "decreased VBG for alert purpose" was 0.93, shown as 93% DoC on screen in Figure 2.

It may look complicated at first glance, but is not. The basic consideration is that all linguistic concepts have inherently unsharp borders. This lack of sharpness is formalized by applying fuzzy sets to the definition of these linguistic concepts [8, 19–21], and is retained for further processing through the entire inference network until the final results have been computed.

Table 2 shows five examples of "classic" surveillance definitions as opposed to the corresponding "softer" clinical alert criteria.

## 4. Discussion

The "classic" surveillance definitions are consented criteria from infection control organizations, developed to count patient cases with and without HAIs. The HAI definitions and the involved clinical concepts are crisp for this purpose, so that whole-number results can be reported for comparison and quality benchmarking. This crispness is preserved in the definition of MONI's clinical concepts.

In contrast, alert criteria show a gradual transition from one concept to the next (from normal to increased, from absent to present, for instance) to obtain a more fitting clinical picture of the particular patient. The principal aim of alert criteria is to sharpen the perception of imminent infections (potential borderline cases) and changing infectious conditions over time.

**Table 2.** "Classic" surveillance criteria (NEO-KISS) and corresponding clinical alert criteria as applied in MONI-NICU (five examples)

| | **NEO-KISS surveillance** | **clinical alert** |
|---|---|---|
| Increased C-reactive protein | ≥ 2 mg/dl<br>crisp threshold | ≥ 1.5 to 2 mg/dl<br>fuzzy-set-based slope;<br>to catch borderline cases |
| Decreased thrombocytes | < 100,000 /µl<br>crisp threshold | < 80,000 to 120,000 /µl<br>fuzzy-set-based slope;<br>quite more flexible |
| Hyperglycemia | > 140 mg/dl<br>crisp threshold | > 200 to 300 mg/dl<br>fuzzy-set-based slope;<br>direct patient impact |
| Decreased venous blood gas | < −10 mval/l<br>crisp threshold | < −7 to −10 mval/l<br>fuzzy-set-based slope;<br>to catch borderline cases |
| Suspicion of pneumonia | positive finding in tracheal secretion plus<br>further clinical findings | positive finding in tracheal secretion |

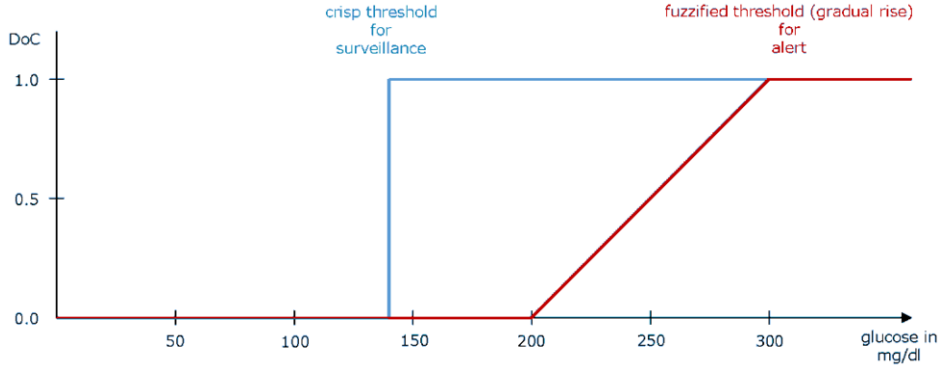


**Figure 3.** Two different hyperglycemia definitions: blue—crisp threshold at 140 mg/dl for surveillance purpose; red—fuzzified threshold (gradual rise) from 200 to 300 mg/dl for alert purpose.

## 5. Legal Considerations

As long as MONI is applied for surveillance purpose—whether for ward, in-hospital, national, or international quality benchmarking—it is not supported as a medical device in accordance with the European Medical Device Directive 93/42/EEC. Even if the surveillance functionality of MONI is used by ward physicians at the patient's bedside to evaluate the patient's clinical condition (with potential impact on diagnosis and therapy), the intended use of MONI—as defined by the manufacturer—is strictly confined to surveillance.

MONI's alert component differs in this regard. The medical purpose here—as defined by the manufacturer—is to alert the attending physician, identify infection as early as possible, and incorporate the fact in the patient's treatment and care. Thus, the alert component is a medical device.

At present, the application of MONI's alert part at the VGH/MUV is under clinical evaluation. It is being used and tested by several key clinical users, who have received appropriate instructions.

## 6. Conclusion

With improved and newly developed components, MONI is able to either report retrospectively on HAIs according to "classic" HAI surveillance definitions, or support clinical ward and bedside work in the form of CDS, overviews of complex matters, alerts, and reminders. Especially the CDS functions require the ongoing implementation of up-to-date clinical knowledge for the purpose of providing maximum clinical benefit to the patient. This approach helps to bridge the gap between "classic" surveillance definitions of HAIs and more clinically oriented HAI alerts.

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