Plea for Use of Intelligent Information and Communication Technologies in Infection Surveillance and Benchmarking by Healthcare Institutions

Walter Koller[1], Klaus-Peter Adlassnig[2,3], Andrea Rappelsberger[2] and Alexander Blacky[1]
[1]*Clinical Institute of Hospital Hygiene, Medical University of Vienna and Vienna General Hospital, Waehringer Strasse 18-20, 1090 Vienna, Austria*
[2]*Section for Medical Expert and Knowledge-Based Systems, Center for Medical Statistics, Informatics, and Intelligent Systems, Medical University of Vienna, Spitalgasse 23, 1090 Vienna, Austria*
[3]*Medexter Healthcare GmbH, Borschkegasse 7/5, 1090 Vienna, Austria*

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Abstract: Top healthcare and medicine depends on the implementation of best practice methods, which include surveillance of and benchmarking with defined quality indicators. Using healthcare-associated infection (HAI) surveillance as an example, we put forward arguments in favour of automated intelligent information and communication technologies. Assessment studies with our fully automated detection and monitoring system for HAIs not only revealed much higher precision of surveillance results and much less time investment compared with conventional surveillance, but also a potential emerged for amendments and adaptations regarding new input categories or new surveillance outputs desired by clinicians, administrators, and health authorities. In this way, intelligent information and communication technologies are becoming indispensable in building affordable "safety nets" for quality assurance and benchmarking, based on fully automated and intelligent data and knowledge management. These in turn form the backbone of high-level healthcare, patient safety, and error prevention.

1 INTRODUCTION

Health institutions today are confronted with growing demands for documentation, quality assurance, certification, and benchmarking. Many of these tasks are performed and shared within networks and require compliance with predefined criteria and standards. These activities are driven by legal, economical, best practice, and patient safety requirements to address just a few. Having to run such complex systems is the price for us to pay for top healthcare, rehabilitation, and disease prevention we are profiting from in the developed regions of the world.

Doctors and nurses as well as other experts in health institutions carry an increasing workload in entering the huge amount of data required for documentation tasks. We have to accept that these obligations interfere with the genuine medical and humanitarian duties we expect from caregivers, and that such tasks contribute to the exhaustion of medical staff. In turn, we as patients suffer from distracted, overtired, or resigning health personnel. All that unfolds in a climate of growing economical and manpower restrictions.

Intelligent information and communication technologies (ICTs) can be considered as a key factor in overcoming this imminent deadlock of modern health systems and in providing for high and even better quality healthcare.

In order to achieve this goal, data generation and documentation must comply with a few strict rules, and ICT must be linked intelligently with the medical documentation systems of the healthcare institution. Redundant documentation, free text documents, and non-coded data are detrimental. In contrast, a strict culture of coded, concise, and timely data entry (especially in clinical documentation!) and a reproducible, well-

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documented data management combined with modern interface technologies are considered to be particularly promising. They allow for both effective ICT assistance, relieve for, and higher potential of caregivers, experts, and administrators.

We have developed and describe below an intelligent ICT for detection and surveillance of healthcare- associated infections (HAIs) in intensive care medicine, called Moni (Monitoring Of Nosocomial Infections).

2 METHODS

2.1 MONI-ICU and MONI-NICU

MONI-ICU is a clinical detection and monitoring system for HAIs, which has been developed in cooperation with the Vienna General Hospital (VGH) and the Medical University of Vienna (MUV). At present, it monitors ten intensive care units (ICUs) for adult patients at the 2116 bed university hospital.

MONI-NICU is the corresponding system for neonatal intensive medicine. It monitors four neonatal ICUs at the VGH and differs from MONI-ICU in the effect that it uses a different knowledge base especially developed for neonatal patients.

An early version of the MONI system is described in Chizzali-Bonfadin et al. (1995). MONI is a fusion of several methodologies drawn from artificial intelligence, fuzzy set theory and logic, as well as medical knowledge engineering (Adlassnig et al., 2008; Adlassnig et al., 2009; Blacky et al., 2011).

2.2 Data Sources

The MONI systems have automated access to several data sources: Most important with regard to patients' day-to-day clinical, laboratory, and care data is MONI's access to the intensive care medical information system ICCA, a patient data management system (PDMS) by Philips. For the acquisition of microbiological data, the systems are connected to the laboratory information system (LIS) of the hospital (MOLIS by vision4health), established for the microbiology department. Finally, administrative patient data from the hospital information system (HIS) is used by both the PDMS and the LIS to uniquely identify the patient and hospital stay (i.s.h.med by Siemens).

2.3 Medical Knowledge Bases

Both the MONI-ICU and the MONI-NICU knowledge bases are Arden Syntax 2.9 representations of the HAI definitions used by the European Centre for Disease Prevention and Control (2013), Stockholm, HAI surveillance network and the KISS definitions issued by the German National Center for Surveillance of Nosocomial Infections (2013a), Berlin, respectively.

The Arden Syntax for Medical Logic Modules is a language for encoding medical knowledge that consists of independent modules and is maintained and developed further by Health Level Seven (HL7) International, a standards organization for health data and knowledge. It was developed in order to represent clinical knowledge in a standardized, machine-readable but also human-readable form. Clinical knowledge is captured in Arden Syntax rules or procedures and can be accessed and evaluated through a rule engine. Within the Arden Syntax, individual rules or procedures are organized in medical logic modules (MLMs), each of which contains sufficient knowledge for a single medical decision (Hripcsak, 1994); refer also to Samwald et al. (2012) for further explanation and recent applications.

Most data thresholds in MONI's knowledge bases are fuzzy, i.e., adhering to the principles of the fuzzy set theory and logic, which were first proposed by Zadeh (1965). An early survey on medical diagnosis and fuzzy subsets can be found in Adlassnig (1982). A complete extension of Arden Syntax by fuzzy methodologies is part of the most recent Arden Syntax, version 2.9 (Health Level Seven, 2013).

By making thresholds fuzzy, we permit clinical borderline cases to be evaluated in a more gradual way than the usual binary inclusion or exclusion of a patient with respect to a certain condition would allow. What we formally capture here is the inherent linguistic uncertainty of clinical terms; furthermore, propositional uncertainty – characteristic for certain other clinical situations – is captured by using fuzzy logic.

2.4 Architecture and Processing

The MONI systems are implemented within an automated, data-driven Arden Syntax framework as described in Adlassnig and Rappelsberger (2008).

Data from the above-mentioned data sources is downloaded overnight and stored in the systems'

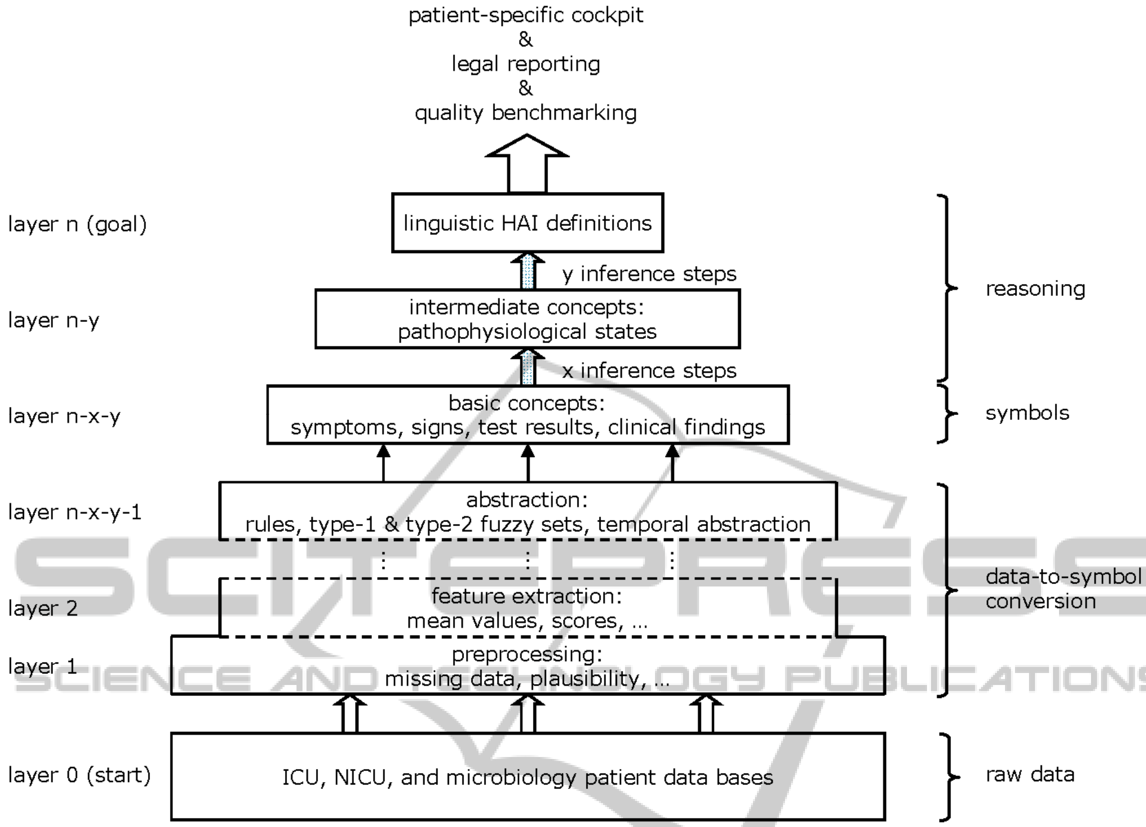

Figure 1: Data processing layers in MONI explaining the way from raw data input [of electronic bedside sensors (e.g., pulse, blood pressure, body temperature), from biochemical laboratory (e.g., leucocyte count, erythrocyte sedimentation rate, C-reactive protein), from microbiology and from routine bedside data entries by ICU staff] to the required specific outputs. HAI: healthcare associated infection, ICU: intensive care unit, NICU: neonatal intensive care unit.

data warehouse. Once the data transfer is completed, the MLMs are executed by the Arden Syntax rule engine. Results and reports can be accessed through local or remote web application interfaces and displayed in a client application or a webpage frontend.

Data processing in MONI is a step-by-step procedure, starting with raw data and advancing from one knowledge level to the next, as depicted in Figure 1.

3 RESULTS

Assessment studies on the MONI systems revealed high precision in surveillance results (sensitivity 87%, specificity 99%, positive predictive value 96%, and negative predictive value 95%). Using automated surveillance systems, time spent with surveillance could be reduced by 85% compared to conventional surveillance methods (de Bruin et al., 2013).

With MONI, there is no need for extra data entry by medical or surveillance personnel. The PDMSs collect data from automated electronic bedside sensors (e.g., pulse, blood pressure, body temperature), from biochemical laboratories (e.g., leucocyte count, erythrocyte sedimentation rate, C-reactive protein) as well as manual routine bedside data entries by intensive care staff (e.g., state of catheter insertion site). Subsequently, MONI draws surveillance-relevant data from PDMSs and microbiology LISs.

We pushed and succeeded in integrating the two MONI systems fully into the information system of our hospital. In doing so, we noticed that the interest of our users (i.e., infection control personnel, clinicians, study personnel) often goes in more than one direction. For example, our intensive care specialists for premature babies exchange their benchmark data with the German NEO-KISS network (German National Center for Nosocomial Infections, 2013b) and with the international Vermont-Oxford Network (2013).

Austrian hospitals tend to exchange their HAI benchmark data not only with the ECDC-affiliated Austrian Surveillance Network ANISS (ANISS Surveillance, 2013), but also with the German counterpart KISS (German National Center for Nosocomial Infections, 2013a) or with the Austrian branch (AUQIP, 2013) of the United-States-based International Quality Indicator Project (IQIP, 2013).

4 DISCUSSION

Having observed infection surveillance for more than two decades, our experience is as follows:

First of all, surveillance systems depending on manual data acquisition are laborious to establish and to maintain, as well as vulnerable; they depend on specifically trained and dedicated personnel and cease to function should these people no longer be available. Since much effort is needed to keep manually operated surveillance systems alive, the potential for their extension or change is rather small.

However, in hospitals where there is a surveillance system in place and working, user requests and wishes to extend the system to additional parameters or to other surveillance networks soon arise. This reflects the growing demand for new and more specialised benchmarking and quality assurance networks in Austria, Europe, and worldwide.

Secondly, in our experience, electronic PDMSs in intensive care medicine are an important field of application for intelligent ICT. If comprehensive clinical, laboratory, and denominator information is timely available from PDMSs, ICT can translate it into the specific formats required by different networks or applications. New or modified data fields may be added, and more than one rule (or rule packages) for automated expert interpretation of the same data set may be implemented.

Two examples: MONI-NICU interprets clinical data according to different sets of rules: NEO-KISS and Vermont-Oxford as well as “clinical alert” criteria, whereas MONI-ICU is designed to provide data interpretation in accordance with ECDC as well as KISS or CDC/NHSN (Centers for Disease Control and Prevention, 2013a) criteria. Thus, MONI users may share their surveillance data with different surveillance networks nationally and internationally.

Thirdly, surveillance systems for HAIs can be considered as mere precursory for newer, much more comprehensive surveillance systems. Recently, wider entities have been introduced, e.g., “ventilator-associated events” instead of “pneumonia” (Centers for Disease Control and Prevention, 2013b) and “readmissions, complications and deaths” which include HAIs, timely microbiological investigation, and appropriate antibiotic therapy (Centers for Medicare & Medicaid Services, 2013).

Figure 2 gives a system view with emphasis on the various outcomes: surveillance results and alerts, reporting, and benchmarking.

Arguments against this approach:

Some people are suspicious that ICT is importing “Big Brother” methods and “NSA strategies” into health care systems. In fact, protected ICT systems (not only of healthcare institutions) themselves are endangered by computer hackers. Much is to be done against fraudulent intrusion and loss of confidentiality.

Others warn against dependency on ICT systems: Some medical experts express their concerns to be challenged or even ruled out by an advanced computer system. Vanishing individual capacity and expertise in understanding what is behind ICT output may be deemed to pave the way into the human expert’s loss of control over medical decisions.

Be such an opposition based on plain fear or on reality, we must deal with it and take it seriously. Some of it may remind us of arguments used against steam engines, railroad, motorcars, or even forks for eating at the time before they were being introduced in every day life. In health and medicine, and especially in hospitals, ICT support still pertains mainly to hospital administration, logistics, and billing. This contrasts with other fields, e.g., production of technical devices, state administration, business, and commerce. Medical expertise for a long time seemed to be kept protected from modern ICT appliances. This is now changing rapidly, at least from ICT’s side. From present medical experts we still see a lack of appreciation for ICTs. Here we face a field of work that cannot be accomplished by technical devices. We can assume that the future generation of medical experts will be much more ready to use ICT appliances. At present, we need to convince “digital non-natives”. This brings us back to deal with and take serious arguments as mentioned above.

Topics we should address: What can we provide to safely prevent fraudulent intrusion into and loss of confidentiality of medical ICT systems? How can we prevent human expert’s loss of control over medical decisions? Who could be the interpreters

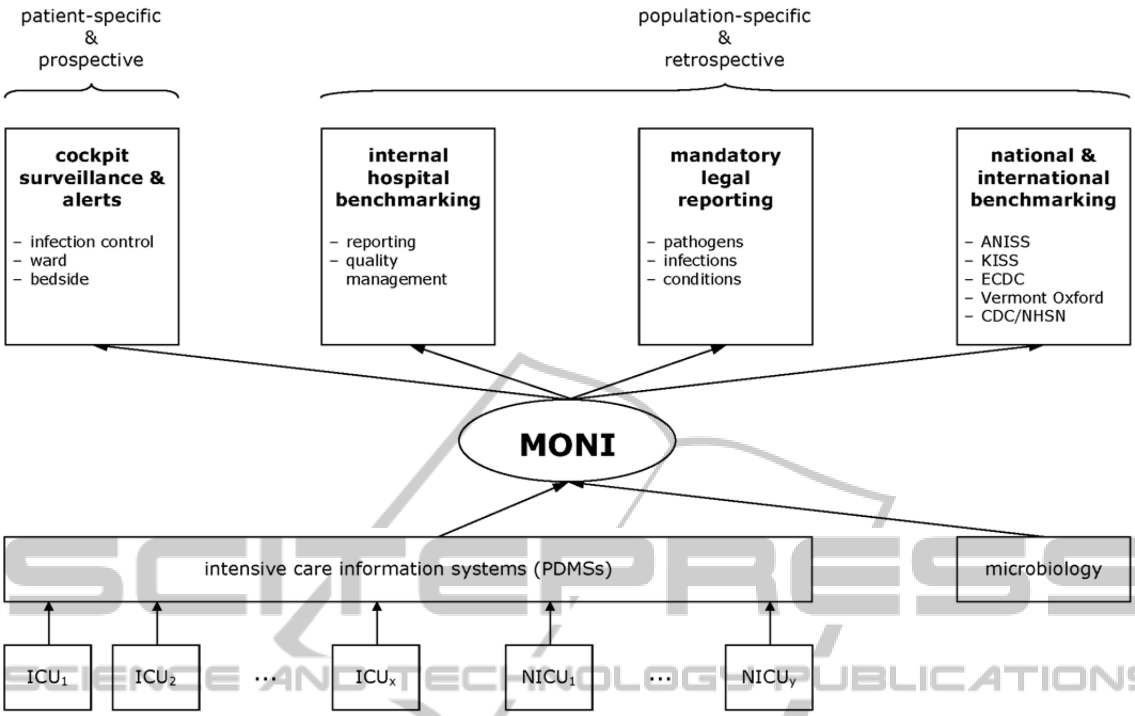

Figure 2: Position of MONI as an intelligent tool for automated processing of specified electronic clinical and laboratory raw data into surveillance or alert information, which – if required – is outputted in appropriate formats for QM, for internal or external benchmarking, or for mandatory legal reporting. ICU: intensive care unit for adults, NICU: neonatal ICU.

between clinical experts and ICT specialists and how could they act successfully in bridging the relevant perceptual gaps? And – one step backwards – how can we accomplish acceptance of surveillance, benchmarking, the implicated use of medical standards, clinical criteria and defined rules even by medical experts who are focussed on “their individual patient with his/her specific history and needs”?

From our own experience, we know to what extent individual scepticism, unfamiliarity with ICT terminology, and unwillingness to dive into the complexity of rule-based ICT decision making can render even powerful ICT tools useless. Still, a significant lack of awareness of the added values provided by surveillance, benchmarking, and related ICT-supportable activities remains.

Finally, as stated in a recent review on electronic surveillance for HAIs by Freeman et al. (2013) in the Journal of Hospital Infection: “... *electronic surveillance systems should be developed to maximize the efficacy of abundant electronic data sources existing within hospitals;*”

and furthermore: “*Electronic surveillance systems should be seen as an opportunity to enhance current surveillance practices. Staff involved in surveillance activities should not feel threatened by advances in this area, but should recognize that these methods can reduce the burdens associated with traditional surveillance methodologies, which will only increase as the emphasis on transparency and public reporting causes increased demand for more information to be reported.*”

5 CONCLUSIONS

Our aim is to implement intelligent ICT systems in health and medicine as supporting tools in an ever growing body of knowledge that has long escaped the mental capacity of a single human being. We need these tools for maintaining and updating health and medical knowledge, for comprehensively, concisely, and timely applying this knowledge to the medical course of a defined patient. They help us in offering knowledgeable proposals and alerts to caregivers and to support growing surveillance, report, and benchmarking duties.

The MONI systems seem to be good examples for this modern ICT approach. They include a data warehouse for storing raw patient data, finally, clinical events automatically inferred from these raw patient data, and, finally, results calculated by using consensual clinical definitions of HAIs. They are connected to an automated inference engine based on fuzzified Arden Syntax, which is adopted as an industry standard by HL7. They serve as intelligent tools that can on the one hand be adapted to varying or newly emerging inputs, and on the other hand to changing output demands. In this way, they are "living" intelligent ICT systems, responsive to environmental changes.

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