Artificial Intelligence in Infection Control—
Healthcare Institutions Need Intelligent Information and Communication Technologies for Surveillance and Benchmarking

Walter KOLLER[a], Andrea RAPPELSBERGER[b], Birgit WILLINGER[c], Gabriel KLEINOSCHEG[d], Klaus-Peter ADLASSNIG[b,d]

[a]Clinical Institute of Hospital Hygiene, Medical University of Vienna and Vienna General Hospital, Währinger Strasse 18–20, 1090 Vienna, Austria

[b]Section for Artificial Intelligence and Decision Support, Center for Medical Statistics, Informatics, and Intelligent Systems, Medical University of Vienna, Spitalgasse 23, 1090 Vienna, Austria

[c]Division of Clinical Microbiology, Department of Laboratory Medicine, Medical University of Vienna and Vienna General Hospital, Währinger Strasse 18–20, 1090 Vienna, Austria

[d]Medexter Healthcare GmbH, Borschkegasse 7/5, 1090 Vienna, Austria

Abstract Modern healthcare and medicine depend on the implementation of best practice, which includes surveillance of, and benchmarking with, predefined quality indicators. Given the automated analysis of microbiological findings and automated surveillance of healthcare-associated infections (HAIs), we put forward arguments in favor of the increasing use of intelligent information and communication technologies for the assessment and surveillance of infection. With MOMO, a modern microbiology analytics software, as well as with MONI, a fully automated detection and monitoring system for HAIs, we registered a much greater precision of analytics and surveillance. The time taken by these systems was much less than that needed for conventional surveillance. We registered the need for timely amendments and adaptations concerning new input categories or new reporting outputs as desired by clinicians, administrators, and health authorities. Intelligent information and communication technologies are thus becoming indispensable in the construction of affordable "safety nets" for quality assurance and benchmarking, based on fully automated and intelligent data and knowledge management. These, in turn, constitute the backbone of high-level healthcare, patient safety, and error prevention.

Introduction

What is infection and what does it mean for our society?
Infection is a disease that is transmissible from one individual to another. The outbreak of an infectious disease is liable to affect a very large number of persons. In

history – and in low-income regions even today – infection has killed myriads of persons and is considerably reducing the life expectancy of human beings [1, 2]. With the advent of penicillin and other antibiotics, the menace of bacterial infection has disappeared from our minds, and new options have emerged. These include extended surgical procedures and highly invasive treatments for otherwise disabling or even deadly conditions, industrial livestock farming, and many other blessings from modern science which we now take for granted in many regions of the world. Regrettably, but inevitably, resistant microorganisms have appeared and are threatening the success we have achieved thus far. The development of new drugs has always been followed by the emergence of new resistances. Today we are confronted with the global spread of multi- and even omni-resistant pathogens.

The role of microbiological diagnostic procedures in the treatment and prevention of infectious disease

Targeted and effective antibiotic therapy is a cornerstone of infection therapy and the prevention of its spread. This concerns the spread of pathogens as well as genes conferring resistance. The diagnostic methods of microbiology are needed to identify pathogens as well as their resistance potential (specimen collection; microscopic investigation, culture, and/or molecular techniques such as polymerase chain reaction (PCR) for the identification of pathogens and their toxins or resistance genes; reporting to the physician). Microbiology reports are not only indispensable for the individual patient's treatment. The information they provide is invaluable for epidemiology, surveillance, and other population-based services in human and veterinary medicine as well as food and water hygiene. Such information includes in-house reporting, regional, national, and international spread of pathogens and their resistances, evidence-based support for prudent use of antibiotics (antibiotic stewardship programs), epidemiological networking, and quality benchmarking.

The role of electronic data and knowledge management

Due to the growing complexity of modern health management, it is dependent to an increasing extent on data-driven guidance and decisions. Electronic data and medical knowledge management have become indispensable in these fields [3, 4].

Implications for medical staff

The management of the large body of data required for documentation signifies a substantial workload on doctors, nurses, and other experts in health institutions. These obligations interfere with the actual medical and humanitarian services we expect from caregivers, and contribute to the exhaustion of medical staff. Patients, in turn, suffer from distracted, overtired, or apathetic health personnel. All of these factors exist in a climate of growing economic and personnel restrictions [5].

The role of intelligent information and communication technologies in infection control

Well-designed and intelligent information and communication technologies (ICTs) are those that avoid unnecessary manual data entry, can be integrated smoothly into clinical workflows, and provide self-explanatory relevant information. By fulfilling these requirements, such technologies help in providing high-quality healthcare [6]. For more than twenty years now, we have been developing highly automated intelligent tools for the analysis of diagnostic microbiology reports [7] as well as for the detection and surveillance of healthcare-associated infections (HAIs) [8-10].

The aim of this paper is to present arguments in favor of the increasing use of intelligent information and communication technologies for the prevention and control of infection. Two applications – MOMO (Monitoring of microorganisms) and MONI (Monitoring of nosocomial infections; *nosocomial* refers to *originating in a hospital*) – which support daily patient care will be presented to emphasize these arguments. First, the respective scope of each application will be explained. Second, the positive effects of these two systems on the treatment of patients will be described. The report is concluded with a critical discussion on the use of intelligent ICTs in healthcare.

Methods

MOMO and MONI are intelligent ICT systems for surveillance, reporting, and benchmarking in healthcare institutions

MOMO is a microbiology analytics and clinical tool for analyzing and reporting pathogens and antimicrobial resistances (AMR) [7, 11]. MONI is an ICT system for the automated detection and surveillance of HAIs in intensive care medicine [12, 13]. Both tools are currently in use (MONI only test-wise) at the Vienna General Hospital (VGH), which is the hospital of the Medical University of Vienna (MUV).

MOMO

MOMO is a microbiology analytics software that provides complete information on the occurrence, frequency distribution, and resistance of pathogens in a hospital. It accommodates all data items available in modern microbiological laboratories: bacteria and fungi including AMR profiles, PCR results, serology results, toxins, microscopy results, remarks accompanying the request sent, on the results, the time of collection of material, their entry into the laboratory, and several others. MOMO's QuickScan functionality provides immediate overviews of the data of the individual patient. It serves as a rapidly usable clinical tool for the attending physician. The analyzed data is updated on a daily basis. Via FlexScan, the 58 different query parameters provide a high degree of flexibility for clinical quality management (QM), administrative queries, and research questions. User-defined query templates facilitate detailed customized reporting and benchmarking. MOMO is embedded into the clinical and laboratory environment: new data are provided once a day by the microbiology laboratory information system (microLIS) and the administrative hospital information system (HIS) (patient denominators). Sources of terminology for text processing include the codes for the requester, specimen type, and antibiotic/antimycotic drugs. Microbiological results – as a special feature of MOMO – are managed by text rather than by code. A specified MOMO thesaurus management system provides this thesaurus service, thus keeping pace with unexpected changes or additional entities in microbiological terminology [7]. Specific artificial intelligence (AI) components of the software include the text processing of microbiological terms as well as knowledge-based AI for alerts or interpretations of microbiological findings. Figure 1 shows the overall structure of MOMO.

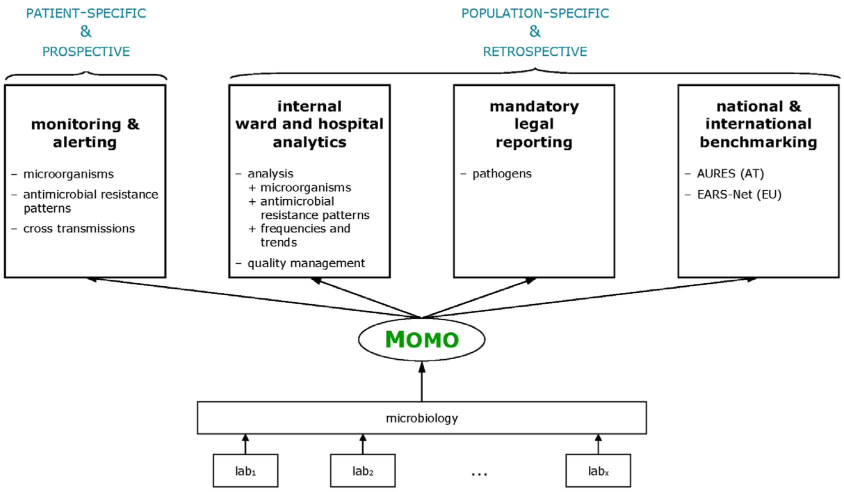

Fig. 1. Position of MOMO as a comprehensive tool for automated processing of microbiology lab report data into surveillance or alert information, which can be provided as output for patient-specific monitoring/alerting as well as population-specific services, such as ward and hospital analytics, QM, internal or external benchmarking, or mandatory legal reporting.

Changes in the management of microbiology terms

In using MOMO, we were confronted with the fact that microbiology reports contain terms unknown to the thesaurus. These could not be sorted in automatically, thus rendering MOMO analyses partly incomplete. This apparently simple problem was complicated by the fact that the thesaurus codes of the microLIS were sometimes overrun by free text entries of lab staff. These free text entries were displayed as readable text in 'pdf' microbiology reports to physicians only. We modified the analytics software MOMO in that microbiology terms could be managed by text processing rather than by code. Microbiological results containing textual elements unknown to the thesaurus that could not be processed automatically were flagged for subsequent assignment. With this change in place, a human expert assigned the elements to the respective existing thesaurus elements or created new ones. We measured the positive effects of this change in a prospective study (see [7]).

MONI

MONI is a fusion of several methodologies drawn from AI, fuzzy set theory and logic, as well as medical knowledge engineering [8-10]. In general, MONI stands for two separate systems, namely MONI-ICU and MONI-NICU, which are clinical detection and monitoring systems for HAIs. MONI-ICU monitors intensive care units (ICUs) for adult patients at the about 1,800-bed Vienna University hospital. MONI-NICU is the corresponding system for neonatal intensive medicine. It monitors neonatal ICUs (NICUs) at the VGH and differs from MONI-ICU in that it uses a different knowledge base specifically developed for neonatal patients.

The MONI systems use automated access to several data sources which provide the day-to-day clinical, laboratory, and care data of patients:

- intensive care medical information and patient data management system (PDMS),
- microLIS of the hospital which provides microbiological laboratory findings,
- HIS, from which both the PDMS and the microLIS acquire administrative patient data to uniquely identify the patient and his/her hospital stay.

Figure 2 shows the overall structure of MONI.

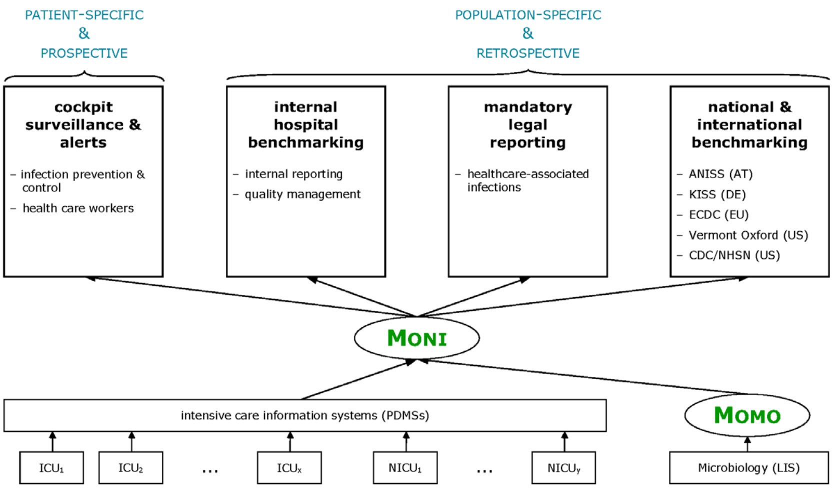

Fig. 2. Position of MONI as an intelligent tool for automated processing of specified electronic clinical and laboratory raw data into surveillance or alert information, which – if required – is outputted in appropriate formats for QM, for internal or external benchmarking, or for mandatory legal reporting.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

Medical knowledge bases

Both, the MONI-ICU and the MONI-NICU knowledge bases are Arden Syntax 2.9 representations [14] of the respective HAI definitions used by ECDC [15], Stockholm, and KISS [16, 17].

The Arden Syntax for Medical Logic Modules (MLMs) is a language for encoding medical knowledge; it consists of independent modules and is maintained and developed by Health Level Seven (HL7) International. Clinical knowledge is captured in Arden Syntax rules or procedures and can be accessed and evaluated through a processing engine. Within the Arden Syntax, individual rules or procedures are organized in MLMs, each of which contains sufficient knowledge for at least a single medical decision [18-20].

The majority of the clinical concept thresholds in MONI's knowledge bases, such as fever, leukopenia, and leukocytosis, are fuzzy. In other words, they permit a gradual transition from one clinical concept to the next. 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 sharply defined condition. What we formally capture here is the inherent linguistic uncertainty of clinical terms. In addition, propositional uncertainty – characteristic of uncertain clinical assertions – is captured by using fuzzy logic.

Architecture and processing

The MONI systems are implemented in an automated, data-driven Arden Syntax framework as described in [21]. Data from the above-mentioned sources are downloaded overnight and stored in the systems' data warehouse. Once the data transfer has been completed, the MLMs are executed by the Arden Syntax processing engine. Results and reports can be accessed through web services and displayed in a webpage frontend.

Data processing in MONI is a stepwise procedure, starting with raw data and advancing from one knowledge level to the next, as shown in Figure 3.

Results

Modification of MOMO thesaurus management

With the modification of microbiological ontologies management as described in the Methods section, MOMO delivered concise analyses. In a prospective set of 196,714 laboratory results, approximately 2.1% contained unassignable textual elements which would otherwise have been ignored in code-based MOMO analyses [7] (see Table 1).

The modification of thesaurus management is incorporated in the last issue of MOMO. In current use the thesaurus is substantiated by synonyms, syntactic deviations, misspellings, and entries not contained earlier, with man-machine interaction of 2–3 hours per week [7]. This approach helps to accommodate both, up-to-date clinical reporting for immediate patient care as well as up-to-date queries for infection surveillance and epidemiology, outbreak management, quality control, benchmarking, and antimicrobial stewardship.

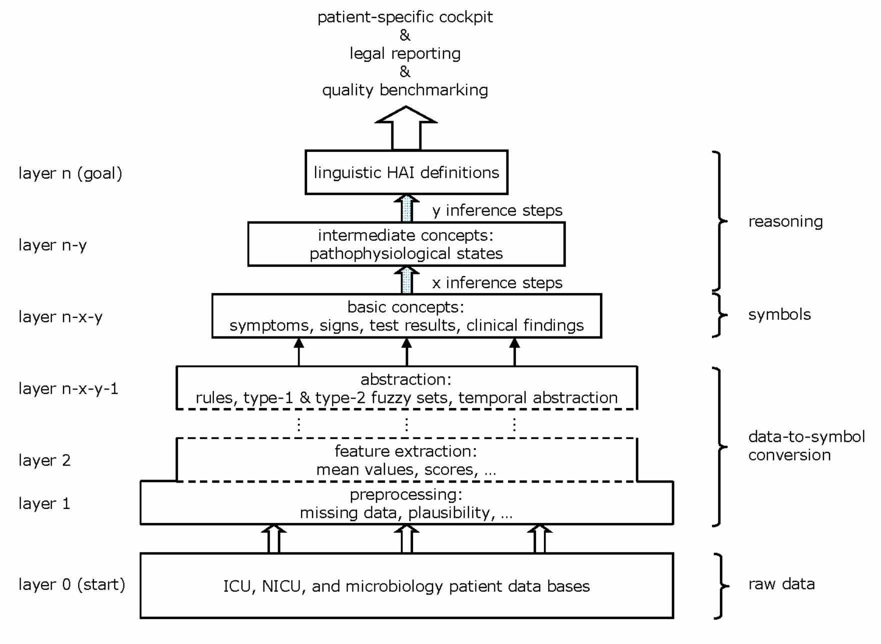

Fig. 3. Data processing layers in MONI explaining the pathway from raw data input [of electronic bedside sensors, such as pulse, blood pressure, body temperature; from the biochemical laboratory, such as leukocyte count, erythrocyte sedimentation rate, C-reactive protein; from microbiology and routine bedside data entries by the ICU staff, to the required specific outputs. HAI: healthcare-associated infection, ICU: intensive care unit, NICU: neonatal intensive care unit.

MONI performance studies

Studies assessing the MONI systems revealed a high degree of precision in surveillance (Table 2). Using automated systems, the time spent on surveillance could be reduced by 85% compared to conventional methods [10, 12].

Inputs from clinical users of the ICT systems

At the VGH, MOMO as well as the two MONI systems are fully integrated into the health IT landscape. By continuous guidance and observation, we noticed that clinical users (infection control personnel, clinicians, research study personnel) started to address new issues. For instance, clinicians asked for possibilities to start MOMO queries from the intensive care PDMS at their wards or at the bedside. Furthermore, intensive care specialists for preterm infants wish to use MONI in order to exchange their benchmark data with the German NEO-KISS network [17].

We observed that hospitals tend to exchange their HAI benchmark data not only with one surveillance network (such as the ECDC-based Austrian Nosocomial Infection Surveillance System [22]), but also with others like the German counterpart KISS [16, 17] or the Austrian quality indicator project AUQIP [23].

Table 1. Figures for 4,191 manually allocated microbiology concepts between October 30, 2018 and August 20, 2019 (approximately 2.1% of 196,714 microbiology results)

Category	Number	Fraction
Culture	580	13.8%
PCR	251	6.0%
Serology	1,603	38.3%
Toxins	264	6.3%
Microscopy	792	18.9%
Miscellaneous	701	16.7%
Total	4,191	100.0%

Table 2. Effectiveness of manual HAI surveillance and electronic surveillance based on the number of detection events (95% CI). PPV, positive predictive value; NPV, negative predictive value.

Surveillance method	Total events generated	Sensitivity %	Specificity %	PPV %	NPV %
Manual surveillance	108	40 (23-59)	94 (86-98)	71 (44-90)	80 (71-88)
Electronic surveillance	106	87 (69-96)	99 (93-100)	96 (81-100)	95 (88-99)

Discussion

Having observed the surveillance of pathogens, AMR, and infections for more than two decades, we summarize our conclusions in the following.

Automated vs. manual data and knowledge management

First, analysis and surveillance systems depending on manual data acquisition are laborious to establish and maintain, as well as vulnerable. They depend on specifically trained and dedicated personnel, and cease to function when such personnel are no longer available. Since substantial effort is needed to keep manually operated analysis or surveillance systems alive, their potential for extension or change is limited.

However, in hospitals equipped with efficient analysis and surveillance systems, users tend to ask for extensions of the systems in terms of additional parameters or connections to other networks. This reflects the growing demand for IT assistance in worldwide clinical benchmarking activities.

Second, in our experience, electronic PDMSs constitute an important field of application for intelligent ICT, especially in intensive care medicine. When PDMSs are able to provide comprehensive clinical, laboratory, and denominator information on a timely basis, ICT can translate the data into the specific formats required by different networks or applications. New or modified data fields may be added, and more than one MLM (or MLM packages) for automated expert interpretation of the same data set may be implemented.

Two examples of these are MONI-NICU and MONI-ICU. MONI-NICU interprets clinical data according to the sets of rules specified in NEO-KISS [17] and Vermont-Oxford [24] as well as "clinical alert" criteria, whereas MONI-ICU is designed to provide data interpretation in accordance with ECDC [15] as well as KISS [16] or CDC/NHSN [25] criteria. Thus, MONI users may share their surveillance data with different surveillance networks nationally and internationally.

Third, surveillance systems for HAIs may be regarded as mere precursors of newer and much more comprehensive surveillance systems. Wider entities have been introduced recently, including "ventilator-associated events" instead of "pneumonia" [26], and "readmissions, complications and deaths" which include HAIs, timely microbiological investigation, and appropriate antibiotic therapy [27].

Figures 1 and 2 provide a system view, emphasizing the various outcomes, be they patient specific such as AMR and HAI alerts, or population related such as information on pathogen transmission, surveillance, or benchmarking.

Arguments against the use of ICT in healthcare

ICT has been suspected of importing "Big Brother" methods into health care systems. In fact, protected ICT systems (not only those of healthcare institutions) themselves are endangered by computer hackers. The problems of fraudulent intrusion and loss of confidentiality are yet to be conclusively resolved.

Others warn against dependency on ICT systems: some medical experts express concerns about being challenged or even overruled by an advanced computer system. The expert's inability to understand the processes behind ICT output may be the reason for a presumed loss of control over medical decisions.

Regardless of whether such opposition is based on plain fear or facts, it needs to be addressed. In part, it is reminiscent of the arguments brought forward against steam engines, the railroad, or motorcars at the time of their introduction in daily life. In health and medicine, and especially in hospitals, ICT support pertains mainly to hospital administration, logistics, and billing. This is in contrast to other fields, such as the production of technical devices, state administration, business, or commerce. Medical expertise appears to have been protected from modern ICT appliances for a long time, but this is changing rapidly. Present-day medical experts still lack appreciation of ICTs. Here we face a field of work that cannot be accomplished by technical devices alone. We may assume that the future generation of medical experts will be much more willing to use ICT appliances. Our current task is to convince "digital non-natives".

From our own experience we know that individual skepticism, unfamiliarity with ICT terminology, and unwillingness to dive into the complexity of computer-based ICT decision-making may render even powerful ICT tools useless. A significant lack of awareness of the added value provided by surveillance, benchmarking, and related ICT-supportable activities remains to be overcome [5].

Finally, as stated in a review on electronic surveillance for HAIs by Freeman et al. [28]:

> "*... 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."*

Conclusion

Our aim is to implement intelligent ICT systems in health and medicine as supporting tools to handle an increasing body of knowledge that has long exceeded the mental capacity of a single human being.

We need such tools for maintaining and updating health and medical knowledge, as well as applying the knowledge to the individual patient comprehensively, concisely, and in a timely manner. The tools make it possible to provide knowledgeable proposals and alerts to caregivers, and support growing surveillance, reporting, and benchmarking duties.

The MOMO and MONI systems are examples of this modern ICT approach. They serve as intelligent tools that can be adapted to varying or newly emerging inputs, as well as changing output demands. Thus, they are "living" intelligent ICT systems, responsive to environmental changes.

References

[1] A.G. Carmichael, Infectious Disease and Human Agency: An Historical Overview. In: Andreae M.O., Confalonieri U., McMichael A.J., editors, *Global Environmental Change and Human Health*, Vol. 106, The Pontifical Academy of Sciences, Vatican City, 2006, pp. 3-46.

[2] P.S. Brachman, Infectious Diseases—Past, Present, and Future, *International Journal of Epidemiology* (2003) **32**(5), 684-686.

[3] K. Kawamoto, C.A. Houlihan, E.A. Balas, D.F. Lobach, Improving Clinical Practice Using Clinical Decision Support Systems: A Systematic Review of Trials to Identify Features Critical to Success, *BMJ* (2005) **330**:765, doi:10.1136/bmj.38398.500764.8F.

[4] A.X. Garg, N.K.J. Adhikari, H. McDonald, M.P. Rosas-Arellano, P.J. Devereaux, J. Beyene, J. Sam, R.B Haynes, Effects of Computerized Clinical Decision Support Systems on Practitioner Performance and Patient Outcomes, *Journal of the American Medical Association* (2005) **293**(10), 1223-1238.

[5] W. Koller, K.-P. Adlassnig, A. Rappelsberger, A. Blacky, Plea for Use of Intelligent Information and Communication Technologies in Infection Surveillance and Benchmarking by

Healthcare Institutions, In: Bienkiewicz M., Verdier C., Plantier G., Schultz T., Fred A., Gamboa H., editors, *Proceedings of the 7th International Conference on Health Informatics (HEALTHINF 2014)*, SCITEPRESS, Portugal, pp. 399-404.
[6] D.D. Rhoads, V. Sintchenko, C.A. Rauch, L. Pantanowitz, Clinical Microbiology Informatics, *Clinical Microbiology Reviews* (2014) **27**(4), 1025-1047.
[7] W. Koller, G. Kleinoscheg, B. Willinger, A. Rappelsberger, K.-P. Adlassnig, Augmenting Analytics Software for Clinical Microbiology by Man-Machine Interaction, In: Ohno-Machado L., Séroussi B., editors, *MEDINFO 2019: Health and Wellbeing e-Networks for ALL – Proceedings of the 17th World Congress on Medical and Health Informatics*, Studies in Health Technology and Informatics, Vol. 264, IOS Press, Amsterdam, 2019, pp. 1243-1247.
[8] K.-P. Adlassnig, A. Blacky, and W. Koller, Fuzzy-Based Nosocomial Infection Control, In: Nikravesh M., Kacprzyk J., Zadeh L., editors, *Forging New Frontiers: Fuzzy Pioneers II*., Springer, Berlin, 2008, pp. 343-349.
[9] K.-P. Adlassnig, A. Blacky, W. Koller, Artificial-Intelligence-Based Hospital-Acquired Infection Control, In: Bushko R., editor, *Strategy for the Future of Health,* Studies in Health Technology and Informatics, Vol. 149, IOS Press, Amsterdam, 2009, pp. 103-110.
[10] A. Blacky, H. Mandl, K.-P. Adlassnig, W. Koller, Fully Automated Surveillance of Healthcare-Associated Infections with MONI-ICU – A Breakthrough in Clinical Infection Surveillance, *Applied Clinical Informatics* (2011) **2**(3), 365-372.
[11] Medexter Healthcare GmbH [Internet]. Vienna: Medexter Healthcare; c2019 [cited 2019 Jul 12]. Momo. Available from: https://www.medexter.com/products-and-services/clinical-solutions/microbiology-and-amr.
[12] J. de Bruin, K.-P. Adlassnig, A. Blacky, H. Mandl, K. Fehre, W. Koller, Effectiveness of an Automated Surveillance System for Intensive Care Unit-Acquired Infections, *Journal of the American Medical Informatics Association* (2013) **20**(2), 369-372.
[13] Medexter Healthcare GmbH [Internet]. Vienna: Medexter Healthcare; c2019 [cited 2019 Jul 12]. Moni. Available from: https://www.medexter.com/products-and-services/clinical-solutions/infection-control.
[14] Health Level Seven International. The Arden Syntax for Medical Logic Systems, Version 2.9, March 2013 [Internet]. Ann Arbor: Health Level Seven International; 2013 [cited 2019 July 1]. Available from: https://www.hl7.org/implement/standards/product_brief.cfm?product_id=290.
[15] European Centre for Disease Prevention and Control [Internet]. Solna: European Centre for Disease Prevention and Control; c2019 [cited 2019 Jul 10]. Available from: http://www.ecdc.europa.eu/en/Pages/home.aspx.
[16] German National Center for Surveillance of Nosocomial Infections. Berlin: Institute of Hygiene and Environmental Medicine at Charité University Medicine Berlin; [cited 2019 Jul 10]. ITS-KISS. Available from: https://www.nrz-hygiene.de/surveillance/kiss/its-kiss/.
[17] German National Center for Surveillance of Nosocomial Infections. Berlin: Institute of Hygiene and Environmental Medicine at Charité University Medicine Berlin; [cited 2019 Jul 10]. NEO-KISS. Available from: http://www.nrz-hygiene.de/surveillance/kiss/neo-kiss/.
[18] G. Hripcsak, Writing Arden Syntax Medical Logic Modules*, Computers in Biology and Medicine* (1994) **24**(5), 331-363.
[19] M. Samwald, K. Fehre, J. de Bruin, K.-P. Adlassnig, The Arden Syntax Standard for Clinical Decision Support: Experiences and Directions, *Journal of Biomedical Informatics*, (2012) **45**(4), 711-718.
[20] K.-P. Adlassnig, A. Rappelsberger, Medical Knowledge Packages and Their Integration into Health-Care Information Systems and the World Wide Web, In: Andersen S.K., Klein G.O., Schulz S., Aarts J., Mazzoleni M.C., editors, *eHealth Beyond the Horizon–Get IT There. Proceedings of the 21st International Congress of the European Federation for Medical Informatics (MIE 2008)*, Studies in Health Technology and Informatics, Vol. 136, IOS Press, Amsterdam, pp. 121-126.
[21] K.-P. Adlassnig, K. Fehre, Service-Oriented Fuzzy-Arden-Syntax-Based Clinical Decision Support, *Indian Journal of Medical Informatics* (2014) **8**(2), 75-79.

[22] Universitätsklinik für Krankenhaushygiene und Infektionskontrolle der Medizinischen Universität Wien [Internet]. Wien: Medizinische Universität Wien; [cited 2019 Jul 10] ANISS - Surveillance. Available from: https://www.meduniwien.ac.at/hp/krankenhaushygiene/forschung-lehre/aniss-surveillance/.
[23] Institut für Pflege und Gesundheitssystemforschung [Internet]. Linz: Johannes Kepler Universität Linz; [cited 2019 Jul 10] AUQIP. Available from: http://www.ipg.uni-linz.ac.at/fr_leiste_proj.htm.
[24] Vermont-Oxford Network [Internet]. Burlington: Vermont-Oxford Network; [cited 2019 Jul 10]. Available from: https://public.vtoxford.org/.
[25] Centers for Disease Control and Prevention [Internet]. Atlanta: Centers for Disease Control and Prevention; [cited 2019 Jul 10] National Healthcare Safety Network (NHSN). Available from: https://www.cdc.gov/nhsn/index.html.
[26] Centers for Disease Control and Prevention [Internet]. Atlanta: Centers for Disease Control and Prevention; [cited 2019 Jul 10] Surveillance for Ventilator-Associated Events. Available from: https://www.cdc.gov/nhsn/acute-care-hospital/vae/index.html.
[27] Centers for Medicare & Medicaid Services [Internet]. Baltimore: Centers for Medicare & Medicaid Services [cited 2019 Jul 10] Medicare.gov, The Official U.S. Government Site for Medicare. Available from: https://www.medicare.gov/.
[28] R. Freeman, L.S.P. Moore, L. Garcia Alvarez, A. Charlett, A. Holmes, Advances in Electronic Surveillance for Healthcare-Associated Infections in the 21st Century: A Systematic Review, *Journal of Hospital Infection* (2013) **84**(2), 106-119.