THE ORIGINS AND DEVELOPMENT OF THE USE OF COMPUTER TECHNOLOGY IN THE FIELD OF EPIDEMIOLOGY IN THE SLOVAK REPUBLIC
POČIATKY A ROZVOJ VYUŽITIA VÝPOČTOVEJ TECHNIKY V OBLASTI EPIDEMIOLÓGIE V SLOVENSKEJ REPUBLIKE

KOLOŠOVÁ Andrea[1], HRUŠKOVÁ Mária[2,3], OLEÁR Vladimír[2,3], KAŠLÍKOVÁ Katarína[2], KRIŠTÚFKOVÁ Zuzana[1], ŠTEFKOVIČOVÁ Mária[2], LITVOVÁ Slavka[2]

[1] *Slovak Medical University, Department of Epidemiology, Bratislava, Slovakia*
[2] *Faculty of Healthcare, Alexander Dubček University of Trenčín, Trenčín, Slovakia*
[3] *Department of Occupational Health Service, ŽILPO s.r.o., Žilina, Slovakia*

ABSTRACT
The discipline of epidemiology is concerned with the study of the occurrence and distribution of health-related conditions and phenomena in specified populations. This includes an investigation of the determinants of these phenomena and the application of this knowledge in the control of health problems. The fundamental methodology employed in epidemiological research is epidemiological surveillance. This can be defined as "the continuous, systematic collection, analysis, and interpretation of health-related data and their timely dissemination to the concerned entities authorised to act on the matter". One of the key objectives of an epidemiological surveillance system is to facilitate the rapid utilisation of the information collected for the purpose of early warning of an epidemic, thereby enabling effective and rapid control of an outbreak. In this regard, the monitoring of communicable diseases constitutes a national responsibility within the health system. The necessity for extensive epidemiological data collection for the purpose of quality surveillance, coupled with the requirement to archive and process said data for analytical purposes, renders this practically impossible without the use of computer technology and information technology. In the Slovak Republic, the initial electronic registry that collected and recorded epidemiological data on communicable diseases (ISPO, Information System of Communicable Diseases) was implemented in 1975. Since 1991, it has been superseded by a new database system, EPIS (Epidemiological Information System). In addition to this system, the ISID (Information System for Immunization of Children) was employed at the local level for the purpose of recording childhood vaccinations. In Slovakia, the utilisation of information technology in public health, including epidemiology, does not align with the prevailing trends in big data processing. Furthermore, the available epidemiological data are not being employed in an optimal and meaningful manner. Despite the availability of data, the utilisation of artificial intelligence (AI) in epidemiological data processing remains minimal. In the Slovak Republic's health system, numerous electronic registries and systems are in operation across various health organisations, including the Public Health Office SR (UVZ SR), health insurance companies, and the National Centre for Health Information (NCZI), among others. These systems are oriented towards the collection, recording, and evaluation of data and information on a range of diseases and conditions, or groups of diseases. However, it is not uncommon for data to be collected in multiple instances, resulting in potential duplication and inconsistencies. The registries are not interlinked, which precludes the possibility of reusing information that has already been collected. In the current situation, artificial intelligence appears to be an effective solution in public health and the protection of public health. It can be used to process and analyse large datasets from health registries and systems, and to produce a solution design and prognosis of the evolution.

Key words: Epidemiology. Public health. Registries. Information systems. Artificial intelligence.

ABSTRAKT
Disciplína epidemiológia sa zaoberá štúdiom výskytu a distribúcie stavov a javov súvisiacich so zdravím v špecifikovaných populáciách. To zahŕňa skúmanie determinantov týchto javov a aplikáciu týchto poznatkov pri kontrole zdravotných problémov. Základnou metodikou používanou v epidemiologickom výskume je epidemiologický dohľad. Možno ho definovať ako „nepretržitý, systematický zber, analýzu a interpretáciu údajov týkajúcich sa zdravia a ich včasné rozširovanie dotknutým subjektom oprávneným v danej veci konať“. Jedným z kľúčových cieľov systému epidemiologického dohľadu je uľahčiť rýchle využitie informácií zozbieraných na účely včasného varovania pred epidémiou, čím sa umožní účinná a rýchla kontrola prepuknutia choroby. V tomto ohľade predstavuje monitorovanie prenosných chorôb národnú zodpovednosť v rámci zdravotného systému. Nevyhnutnosť rozsiahleho zberu epidemiologických údajov na účely kvalitného dozoru spolu s požiadavkou na archiváciu a spracovanie uvedených údajov na analytické účely to prakticky znemožňuje bez použitia výpočtovej techniky a informačných technológií. V Slovenskej republike bol prvý elektronický register, ktorý zbieral a zaznamenával epidemiologické údaje o prenosných ochoreniach (ISPO, Informačný systém prenosných ochorení) zavedený v roku 1975. Od roku 1991 ho nahradil nový databázový systém EPIS (Epidemiologický informačný systém). Okrem tohto systému sa na lokálnej úrovni využíval ISID (Informačný systém pre očkovanie detí) na účely evidencie očkovania detí. Využitie informačných technológií vo verejnom zdravotníctve, vrátane epidemiológie, na Slovensku nezodpovedá prevládajúcim trendom v spracovaní veľkých dát. Okrem toho dostupné epidemiologické údaje sa nevyužívajú optimálnym a zmysluplným spôsobom. Napriek dostupnosti údajov zostáva využitie umelej inteligencie (AI) pri spracovaní epidemiologických údajov minimálne. V zdravotníctve Slovenskej republiky je v prevádzke množstvo elektronických registrov a systémov naprieč rôznymi zdravotníckymi organizáciami vrátane Úradu verejného zdravotníctva SR (ÚVZ SR), zdravotných poisťovní a Národného centra zdravotníckych informácií (NCZI). Tieto systémy sú orientované na zber, zaznamenávanie a vyhodnocovanie údajov a informácií o celom rade chorôb a stavov alebo skupín chorôb. Nie je však nezvyčajné,

že sa údaje zbierajú vo viacerých prípadoch, čo vedie k možnej duplicite a nezrovnalostiam. Registre nie sú prepojené, čo vylučuje možnosť opätovného použitia už zhromaždených informácií. Umelá inteligencia sa v súčasnej situácii javí ako efektívne riešenie v oblasti verejného zdravia a ochrany verejného zdravia. Môže sa použiť na spracovanie a analýzu veľkých súborov údajov zo zdravotných registrov a systémov a na vytvorenie návrhu riešenia a prognózy vývoja.

Kľúčové slová: Epidemiológia. Verejné zdravotníctvo. Registre. Informačné systémy. Umelá inteligencia.

INTRODUCTION

Epidemiology (from the Greek words 'epi' and 'demos', meaning 'on' and 'people' respectively, and 'logos', meaning 'science') is a discipline of public health that is generally defined as a medical discipline that studies the distribution of health and disease in a population for the purpose of solving health problems in that population [1].

The natural empirical progression of thought from observation to the systematic placing of one phenomenon to another, their careful recording, counting, and finally logical reasoning that places facts in such a context as to explain the causes, occurrence, and associations of the diseases under observation – this is epidemiological thinking, the epidemiological approach to diseases of their occurrence and their causes, regardless of etiology [2].

The foundations of this definition were first established by Hippocrates, who emphasised the importance of observing the individual, population, contributing factors, aetiology, and the context in which diseases occur, particularly in the case of mass outbreaks. The International Epidemiological Association (IEA) presents a definition by the Canadian epidemiologist John M. Last, which states that *"epidemiology is the medical discipline concerned with the study of the distribution and determinants, conditions and phenomena associated with health in specified populations, and also with the application of the results of this study to the control of health problems"* [3, 4].

Classical epidemiology is founded upon the capacity to synthesise information and knowledge from the full spectrum of medical disciplines and non-medical specialities. The fundamental tenets of the epidemiological method are observation, descriptive analysis, data analysis, interpretation of results, design and evaluation of measures.

Clinical epidemiology is the application of epidemiological principles and methods to clinical practice. The focus is on populations of patients with a specific disease, and the knowledge gained is then applied to individual patients. This may include monitoring the length of recovery or the effectiveness of treatments for particular diseases. Molecular epidemiology employs molecular biology techniques in epidemiological studies, for example, by identifying the genotype of a pathogenic microorganism, which enables the tracking of its spread in an epidemic. Incorrect or inadequate formulation of working hypotheses, flawed or erroneous evaluation of descriptive data, and the subsequent use of inaccurate or misleading risk factors can result in erroneous conclusions regarding the development of health (anti-epidemic) measures and interventions, which may have serious implications for public health. The ultimate consequence may be a pervasive disillusionment with epidemiological studies and initiatives, and the measures they engender [5].

Furthermore, from this perspective, epidemiology is an optimal medical discipline for the utilisation of information systems, registries and the application of artificial intelligence as an auxiliary and potentially the primary working tool for the analysis and particularly the prediction of epidemic situations. Surveillance represents the foundation of contemporary epidemiological practice, facilitating the acquisition, analysis and design of solutions based on data. As defined by the World Health Organization (WHO), its role is *"to utilize all appropriate epidemiological and other methods as a guide for disease control"*. Public health surveillance systems may be classified as either passive or active. Passive surveillance entails the regular and ongoing reporting of diseases and conditions by all health facilities within a specified geographical area. An active surveillance system is one in which health facilities are visited and healthcare providers and medical records are reviewed with a view to identifying a specific disease or condition [6].

In order to fulfil the requirements of disease surveillance as defined by the World Health Organisation (WHO), the following criteria must be met:

- a precise definition and classification of the disease being monitored is essential,
- accurate and standard laboratory techniques must be established for the diagnosis of the disease itself and for monitoring the characteristics of the aetiological agent,
- data sources must be identified and data systems and information flows provided,

- the continuous collection and classification of data and all necessary information on the process of spread of the disease, monitoring of the conditions that influence this process,
- analysis and presentation of epidemiological data,
- the central evaluation of the information and the establishment of a system of measures that would lead to containment, eradication or at least effective control of the disease [7].

Professor Raska posits that surveillance encompasses a multitude of additional elements, including morbidity, mortality/mortality, geographic distribution, detailed characterisation of agents, molecular epidemiology, global epidemiology, population immunity and prevention, prophylaxis, and vaccination strategies [8].

There is consensus among international institutions on the attributes of a surveillance system that require continuous evaluation. These include simplicity, flexibility, acceptability, sensitivity, predictive value and timeliness [9].

An effective disease surveillance system furnishes data for the planning, implementation, monitoring and evaluation of public health intervention programmes. Epidemiological surveillance of communicable diseases constitutes an integral component of the public health system, which should be an integral part of the global health information system.

Electronic registries - systems in epidemiology in Slovakia

The concept of utilising information technology in the field of epidemiology in Slovakia has a long historical precedent. The inaugural comprehensive electronic system for the recording and processing of data on communicable diseases at the national level (Czechoslovakia) was established in 1975. The central workplace, equipped with JSEP (Unified System of Electronic Computers) R1, R2 and subsequently SMEP (System of small electronic computers) computers, was operated at the Regional Hygienic Station in Ostrava, where the head of the Department of Epidemiology was Vladimír Plesník, M.D. The head of the computer centre was Vilém Holáň, M.D., CSc., and Čestmír Beneš, M.D., M.Sc. The system operated on the basis of weekly reports of communicable diseases from all sanitary stations within Czechoslovakia, which were initially transmitted by telex-dial and coded punched tape, and subsequently by floppy disks (5-inch and then 3-inch). The Communicable Disease Information System (ISPO) was employed with minor modifications until 1989, enabling the input of 16 variables pertaining to a patient with a communicable disease within a single report [10].

Furthermore, the system permitted the documentation and monitoring of widespread illnesses, including influenza and influenza-like illnesses, as well as other prevalent diseases such as varicella.

In 1988, an electronic registry based on personal computers was established in Slovakia under the name Epidemiological Information System (EPIS). The inaugural EPIS system was implemented on a provisional basis at the epidemiology workplaces in Rimavská Sobota (developed by Dušan Béreš, M.D.) and Žilina (Vladimír Oleár, M.D.). The introduction of personal computers into epidemiology was accelerated as a result of this database system, and since 1991, the EPIS system has been implemented in all epidemiology departments in the Slovak Republic. The central workplace was established at the Department of Epidemiology of the Regional Hygienic Station in Banská Bystrica under the leadership of Mária Avdičová M.D. and the head of the KHS computer centre, Františka Hrubá Dr. During this period, the system operated as a distributed system [11].

In 1995, the system was redesigned and modified by Softec, operating as a distributed system under MS-DOS and utilising the International Classification of Diseases (ICD-10). In 2005, the system underwent a redesign under the PHARE programme, resulting in its current form, which includes standard analytical outputs and support programmes. The objective of the PHARE project was to develop a contemporary information system utilising cutting-edge technologies (web interface, resilient database), to align infectious disease surveillance with EU standards, to enhance the collection, processing and analysis of epidemiological data, and to elevate the quality of public information. The system offers an immediate overview of the incidence of communicable diseases reported in Slovakia, as well as in its regions and localities. Furthermore, the system furnishes data regarding the quality of epidemiologists' work, automatically indicating an elevated incidence of monitored communicable diseases in comparison to the anticipated incidence at the level of the Slovak Republic – a phenomenon known as the 'semaphore'. Additionally, it

provides epidemiologists with online access to data on monitored communicable diseases in the Slovak Republic over the past decade.

The EPIS system, with incremental adaptations, remains operational to this day and serves as the fundamental database for communicable disease information within the Slovak Republic. The introduction of electronic recording for epidemiological data has enabled the input of more accurate and reusable data on diseases. All information systems employed in the field of epidemiology utilise the patient's birth number as a classification identifier, followed by the diagnosis number in accordance with the International Classification of Diseases and Conditions.

The EPIS system has recently undergone an upgrade. The latest iteration of the system incorporates an automated connection to microbiological software, thereby facilitating the transmission of data for the reporting of communicable diseases in conjunction with laboratory results. Following the processes of reading and verification, the results are transmitted to the EPIS system in a secure and timely manner. Subsequently, a local epidemiologist conducts an epidemiological investigation and incorporates pertinent epidemiological data into the laboratory reports.

Moreover, the enhanced system enables the execution of multiple automated analyses and the generation of essential data for the implementation of epidemiological measures. Concurrently, it furnishes pertinent institutions with the requisite information and facilitates the publication of data on the Public Health Authority's websites. Connections are currently being established with specific NCZI databases, with a particular focus on electronic surveillance of severe acute respiratory infections (SARI) and vaccination registration.

The second area of communicable disease epidemiology in which the application of computing technology offers significant potential for highly efficient data management is that of the information system used to collate vaccination data. Similarly, the Information System for Immunization of Children (ISID), like the ISPO, was initially developed in Ostrava and introduced locally as early as 1972. The system enabled the recording of data on vaccinations carried out in accordance with the national vaccination programme for children up to the age of 15, while simultaneously generating automated invitations for registered children for subsequent vaccinations.

In Slovakia, a comparable system was implemented in 1982 for the entirety of the Žilina district, based on the experience of Ostrava. Both original systems were operational on SMEP-SM 4/20 mainframe computers running the DOS operating system. Subsequently, an experimental transition to software supported by personal computers was introduced in 1994 in the Trenčín district (Štefkovičová M.D.) under the name ISOP (Information System of Population Vaccination). The aforementioned registry or electronic systems were not incorporated into the Slovak immunization programme due to their lack of acceptance, which was paradoxically demonstrated by pediatricians. The principal advantage of these systems was the capacity to archive data on non-paper records over an extended period, coupled with the ability to process them rapidly. The principal rationale for the implementation of an electronic system for vaccination is the capacity to assess data in real time, thereby facilitating continuous monitoring of immunisation outcomes. This is in contrast to the current practice of manual data processing by vaccinating physicians, which remains a limitation.

The conditions for the introduction of an information system, specifically a vaccination register, are optimal. All outpatient doctors affiliated with the VLD and VLDD are equipped with computer technology and software designed for outpatient use. This technology records all performances, including vaccination, exclusively in electronic format. It also facilitates direct electronic contact with health insurance companies for the purpose of billing. Additionally, doctors and public pharmacies are able to electronically report data regarding the performance of their services to relevant statistical systems. The prescription of vaccines via e-prescription allows for the collection of information about the use of the vaccine. Nevertheless, in practice, the public health sector has not yet utilised the potential of "cross-checking" vaccination data obtained through the conventional method of administrative control of vaccination with the accessible electronic data, for instance, from health insurance companies [12].

Globally, analogous systems, in conjunction with vaccination history, facilitate the entry and documentation of supplementary information about individuals, including details such as occupation or risk factors, the rationale behind vaccine schedu-

ling, and so forth. Electronic immunization registries can then be integrated into an immunization information system, which offers a considerably broader range of potential applications for the data collected [13].

However, for the purposes of epidemiological analysis and prediction of the possibility of an epidemic outbreak, it is essential to have access to high-quality, up-to-date data on the implementation of the immunisation programme, the status of individual and collective immunity. This information is not only crucial for the assessment of the immune status of the population, but also for the cost-effective management, organisation, direction and monitoring of health policy in the field of vaccine-preventable disease.

At the time of the implementation of both systems, no analytical or statistical software was available, and data evaluation was conducted through the use of classical descriptive and statistical methods, with independent data processing. The advent of personal computers and the subsequent availability of statistical software, including Statgraphic, EGRET (Exploration and Graphics for River Trends), and Excel, along with a specialized system developed by the CDC Institute in Atlanta with the support of WHO, EPI Info, marked a significant turning point in the utilization of analytical outputs from processed epidemiological data recorded in the ISP, EPIS, and ISID databases in Slovakia. The individual who initially introduced and subsequently trained others in the use of the EPI Info system in the epidemiology departments of the then Institutes of Hygiene and Epidemiology was Dušan Béreš, M.D. In 2013, the legislative framework for the utilisation of information systems in the healthcare sector was established by Act 153/2013 on the National Health Information System , which, in §4, specifies the information systems and registries currently employed by the healthcare sector [14].

At the national level, the health information system E-health is in operation. This system includes a number of programmes and functions that provide virtually all the necessary epidemiological information for the online assessment of the epidemic situation. This information includes the possibility of determining the trend or risk of an epidemic outbreak.

In addition to the EPIS system, which is under the responsibility of the Office of Public Health of the Slovak Republic (OPH SR), the National Centre for Health Information (NCZI) operates and covers the following areas: The National Registry of Electronic Health Records, the National Cancer Registry, the National Diabetes Mellitus Registry, the National Birth Defects Registry, the National Registry of Circulatory System Diseases, the National Registry of Neurological Diseases, the National Registry of Chronic Lung Diseases, and the National Tuberculosis Registry. The National Arthroplasty Registry, the National Register of Inflammatory Rheumatic Diseases, the National Register of Injuries Requiring Inpatient Health Care, the National Register of Persons Suspected of Neglect, Abuse, and Violence, and the National Register of Assisted Reproductive Technology are also included in the list of national registers. The National Screening Register is another example of a national register [14, 15].

However, the aforementioned systems are currently operated as discrete, standalone registries that are not interlinked, thereby precluding the sharing of information between the databases. In this context, the potential for artificial intelligence systems to significantly influence the use of information from all registries and subsequently provide health authorities (MZ SR, ÚVZ SR, etc.) with both standardised and non-standardised outputs on health and disease in the population is being explored under the supervision of epidemiologists.

CONCLUSION

The application of artificial intelligence presents a novel avenue for the management and analysis of communicable disease data in Slovakia. It enables the effective monitoring of disease spread, the anticipation of epidemic trends, and the optimisation of healthcare system responses. The application of AI has the potential to enhance not only the precision and rapidity of decision-making processes, but also to improve the overall protection of public health. The compatibility with the systems of the European Centre for Disease Prevention and Control (ECDC) will reinforce Slovakia's capacity to respond efficiently to health threats, thereby contributing to the enhancement of public health protection within the European context.

REFERENCES

[1] LAST J.M. *A Dictionary of Epidemiology*. 2000, Fourth edition, 224 pp. Oxford University Press, USA. International Epidemiological Associa-

tion, Inc. ©1983, 1988, 1995, 2001.
[2] WORLD HEALTH ORGANIZATION. Public health surveillance. (accessed January 14, 2016)
[3] NÁRODNÉ CENTRUM ZDRAVOTNÍCKYCH INFORMÁCIÍ. Národné zdravotné registre. Dostupné na: https://www.nczisk.sk/registre/narodne-zdravotne-registre/Pages/default.aspx
[4] *PORTA M. A Dictionary of epidemiology*. 2014, 6th edition. Oxford University Press, USA. International Epidemiological Association, Inc. ©1983, 1988, 1995, 2001, 2008, 2014.
[5] ROTHMAN K.J., GREENLAND S., LASH T.L. *Modern epidemiology*. Third edition, 1998, pp. 758. Lippincott Williams & Wilkins, USA.
[6] WORLD HEALTH ORGANIZATION. "Surveillance for Vaccine Preventable Diseases". World Health Organization: Immunization, Vaccines and Biologicals. Archived from the original. 2014. Retrieved 19 October 2016
[7] WORLD HEALTH ORGANIZATION. Protocol for the assessment of national communicable disease surveillance and response systems: guidelines for assessment teams. 2001. dostupné na: https://iris.who.int/handle/10665/66787
[8] RAŠKA K. The epidemiological surveillance programme. *J Hyg Epidemiol Microbiol Immunol*. 1964; 8: 137-68.
[9] BRAŽINOVÁ A. *Epidemiologické metódy a ich uplatnenie v epidemiológii vybraných ochorení.* Vysokoškolské skriptá. Lekárska fakulta Univerzity Komenského v Bratislave. 2020, 70 s. ISBN 978-80-223-4982-6
[10] OLEAR V., KOHL I. *Informatics systems in Epidemiology of Communicable diseases in Slovak Republic,* IEA meeting, 18.05.1994, Copenhagen
[11] OLEÁR V., KOHL I., ČERVENKA J. *Impact of computers in Expanded programme on Immunisation,* IEA meetinvg, 18.05.1994, Copenhagen
[12] OLEÁR V., KRIŠTÚFKOVÁ Z., KLEMENT C. a kolektív. *Kapitoly z vakcinológie*. Vydavateľstvo PRO Banská Bystrica, 2014, 320 s. ISBN 978-80-89057-52-8
[13] EUROPEAN CENTRE FOR DISEASE PREVENTION AND CONTROL. *Designing and implementing an immunisation information system.* Stockholm: ECDC; 2018.
[14] Zákon č. 153/2013 Z. z. *Zákon o národnom zdravotníckom informačnom systéme a o zmene a doplnení niektorých zákonov.*
[15] ÚSTREDNÝ PORTÁL VEREJNEJ SPRÁVY. eHealth - elektronické zdravotníctvo. Dostupné na: https://www.slovensko.sk/sk/agendy/agenda/_e-zdravotnictvo/