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# Artificial Intelligence Quotient Vol. 4

## The Potential of Artificial Intelligence in the Healthcare Sector

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The partners had no impact on the tone of the report. The report is an unbiased study.

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# About the report

The report consists of an introduction, a collection of expert chapters, a selection implementation examples, and a set of recommendations. In the introduction and the first chapter, the reader can get acquainted with the theoretical concept of artificial intelligence and learn how it works in practice, which may be helpful in the analysis of the content included in subsequent chapters.

The expert chapters have been written by independent experts in their respective fields. They present their views on the potential applications of artificial intelligence – and point out the risks involved. We have tried to make the discussion of the issues covered in the report as reader-friendly as possible. The report can be treated as a whole, but it can also be read as a collection of studies addressing selected areas of particular interest to the reader.

The recommendations offered are a set of suggestions and proposals on the possible directions of further utilization and development of artificial intelligence in the health sector. They are a result of the knowledge, thoughts, and experience of the authors of the report.

The aim of the report is to offer an accessible collection of opinions and recommendations by leading experts in a given field: doctors, specialists, and scholars. It includes a description of the current opportunities for the application of AI methods in the health sector and discusses the prospects and concepts for its development in the coming years.

# Introduction

RYSZARD TADEUSIEWICZ

This report presents the opinions of various experts on the current state of and the future prospects for the development of artificial intelligence (AI) in the health sector. As it seems, AI has already marked its presence in this sector in two distinctly different ways.

One of these ways – or areas – concerns broadly defined planning and management. The health sector experiences a number of organizational, financial, and social problems. Some are similar to those we face in other sectors, others are clearly different. However, what is important in this whole area is to efficiently collect, organize, and use large sets of information, accurately model diverse situations and forecast their progress and development, and make various decisions. AI should be put to use – and can prove very helpful – in all these tasks.

The symbolic area of applications of AI in health sector management and administration is shown in Figure 1 (below), where a person involved in health sector administration and management processes uses a computer system featuring artificial intelligence-based programs – with the programs symbolized by a neural network diagram (other methods are more difficult to illustrate).

Fig. 1. Symbolic representation of AI in health sector management

The other area where the presence of AI in the health sector is already felt but will become even more dominant with time is the area of testing and diagnosing patients, treating and forecasting in specific patient cases, and predicting outcomes. The tasks in which artificial intelligence is to be employed in this area are illustrated in the figures to follow. It was a deliberate decision to present these tasks in a different way in order to clearly distinguish them from those symbolically represented in Figure 1.

Every procedure of medical treatment starts from the acquisition of diagnostic information – imaging (tomography, magnetic resonance, ultrasonography, isotopic methods), but also bioelectrical (ECG, EEG, EMG), biochemical, biomechanical, and many other types of information. At this stage of treatment, artificial intelligence makes it possible to process the acquired images (and other input data) in such

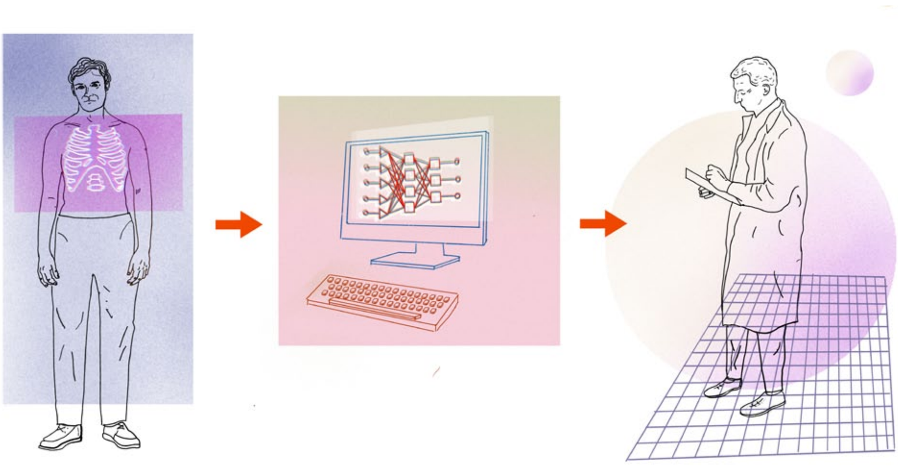


Fig. 2. Artificial intelligence used for data filtering in biomeasurements

a (smart!) way that the physician finds it much easier to interpret the available information – and the interpretation becomes more accurate (Fig. 2).

The results of the biomeasurements reflecting the current condition of the patient's body are an important indication, but they are not the main focus of medical management. The focus is on an accurate diagnosis and effective treatment. But artificial intelligence is highly useful at these stages too.

→ **A computer itself will not make a diagnosis because diagnostic decisions involve liability – i.e. civil and sometimes even criminal liability, which means that this area is and will be the domain of humans.**

Yet, artificial intelligence can be very useful as an advisory system supporting diagnosticians. It can draw one's attention to some details, offer prompts and suggestions, and provide warnings (Fig. 3).

Once the diagnostic decision has been made, it's time for treatment. AI proves to be very useful as a consultant and an advisor (many expert systems are designed for this), but its usefulness does not end here. It is more and more common to see various machines being used to treat patients. The precise and adaptive control of these machines is – and will be – supported by AI-based tools and methods. Such solutions are applied in ionizing or corpuscular radiation therapy (e.g. guided proton beams). AI is also used to control surgical robots, and its wider adoption could translate into a greater availability of ventilators – which are now in high demand. Actually, the problem in treating COVID-19 is not the lack of ventilators, but the small number of doctors who know how to set and control them properly. An AI-enhanced ventilator could be used by less experienced personnel – with great benefit to patients (Figure 4).

Lastly, it seems only fair to mention that physicians make frequent use of the well-known ability of AI to predict the consequences of certain actions. This form of application of AI has already been mentioned in the context of the needs in health sector management (at various levels), but AI can also be a tool to support doctors in choosing the right method to manage and take care of a given patient. Thanks to AI's predictive capabilities, it is possible to predict – even before the treatment starts – if the adopted line of treatment is going to be effective and let the patient... develop another heart attack after they are released from hospital.

Fig. 3. Artificial intelligence as a diagnostician's consultant

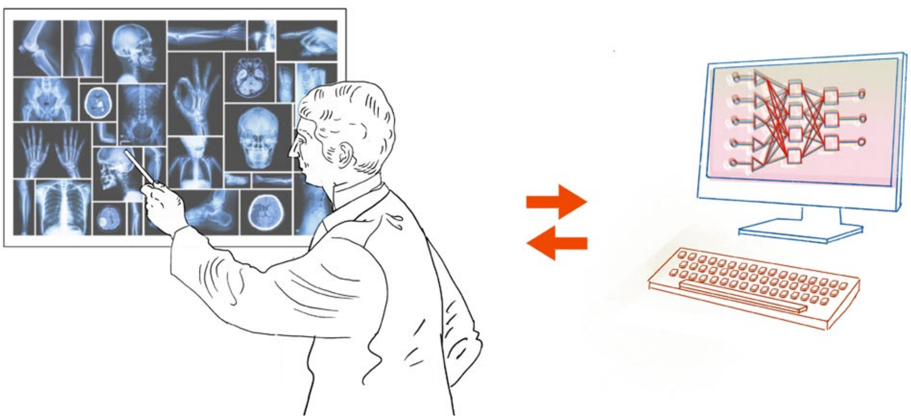
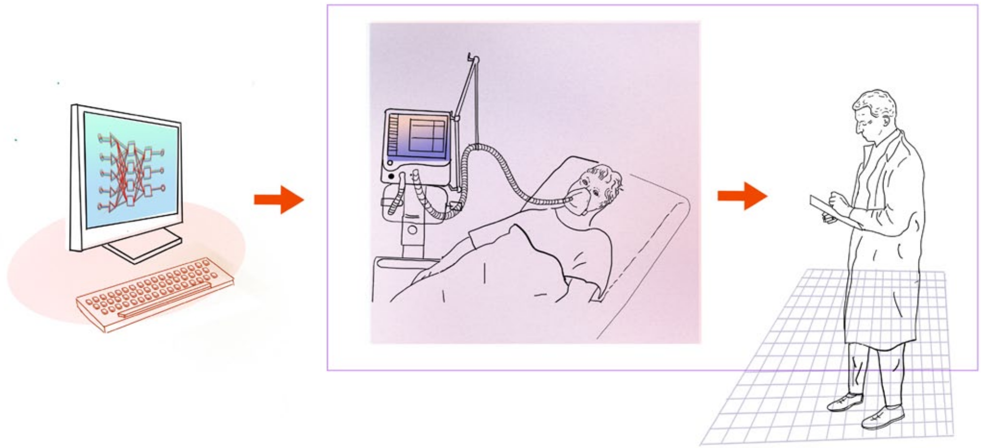


Fig. 4. Artificial intelligence as an assistant in therapy



However, it is also possible to predict that the treatment will have no effect whatsoever and regardless of the efforts made, the outcome will be tragic anyway (Figure 5).

In the latter case, the most rational decision would be to abandon the treatment doomed to failure – for the sake of the patient, who can be spared a lot of suffering, but also because of the costs involved.

We have identified the range of topics addressed in this report. Now, we will now briefly outline the report's contents.

Chapter one presents AI technology with a focus on the most promising methods of its application and foreseeable directions of its development. Chapter two presents selected instances of application of artificial intelligence in medicine and in the health sector in general, illustrated with examples showing what has already been done in this field. Chapter three describes the prospects for financing the research and development of AI in the health sector in Poland with the use of domestic and European funds. Chapter four discusses the ethical and legal challenges of the use of AI in the health sector, along with an in-depth analysis of the EU and Polish strategies applied in this area. The report ends with a set of recommendations.

**RYSZARD TADEUSIEWICZ**

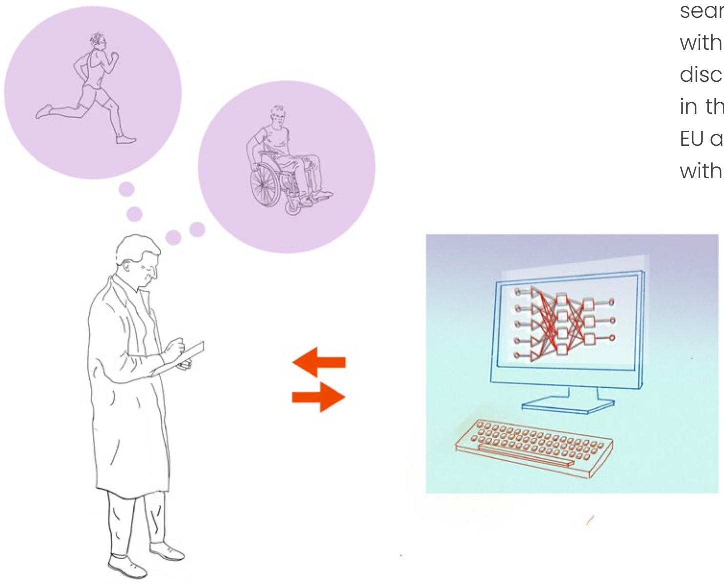


Fig. 5. Artificial intelligence as a tool to predict the results of treatment

**Prof. Ryszard Tadeusiewicz, PhD, DSc, Eng.** – professor of technical sciences, automationist and computer scientist, three times rector of the AGH University of Science and Technology, full member of the Polish Academy of Sciences, correspondent member of the Polish Academy of Arts and Sciences and of several European academies of sciences. Doctor honoris causa of 14 Polish and foreign higher education institutions. Founding member and honorary member of the Polish Information Processing Society, founding member and vice-president of the Polish Artificial Intelligence Society. In addition to conducting research and lecturing at AGH University of Science and Technology, he has taught computer science at Cracow University of Economics, the Pedagogical University of Krakow, and the Pedagogical University and the Jagiellonian University Medical College. His interests have focused on artificial intelligence, especially neural networks. He has made major contributions to the development of methods of computer processing, recognition, and automatic understanding of medical images. Supervisor of several dozen doctoral dissertations, reviewer of several hundred doctoral dissertations, over 150 postdoctoral dissertations, and nearly 150 applications for the conferment of the title of professor. Author/co-author of over 100 books, editor of over 50 books, author of over 1,100 scientific articles and of over 150 editorials. Runs his own website: www.tadeusiewicz.pl.

# Chapter I.

# Artificial intelligence technology

RYSZARD TADEUSIEWICZ

- Artificial intelligence – general characteristics, origin, structure
- Discussion of two groups of artificial intelligence methods, representing two different approaches: symbolic methods (highly formalized) and neural networks (intuitive and based on brain modeling)

The term “artificial intelligence” (AI) might suggest that it is an integral field. In fact, it is a set of very different methods that people have come up with to make machines better address and respond to their needs. The majority of these methods have absolutely nothing in common and there is no easy way to switch from one to the other.

This chapter discusses some of these methods. The criterion of selection was their applicability to the health sector.

The reason for artificial intelligence being so internally complex and heterogeneous is its **origin**. Humans, driven by a need for tools that would serve them better, have reached out to a variety of sources. Figure 1 shows selected sources of knowledge from which artificial intelligence developers draw patterns and inspiration. Actually, there are many more of these sources, but the ones shown are those that seem to have had the greatest impact on the emergence and development of the field discussed here.

The earliest attempts to make machines ‘behave’ intelligently involved the use of **symbolic calculations** (see Figure

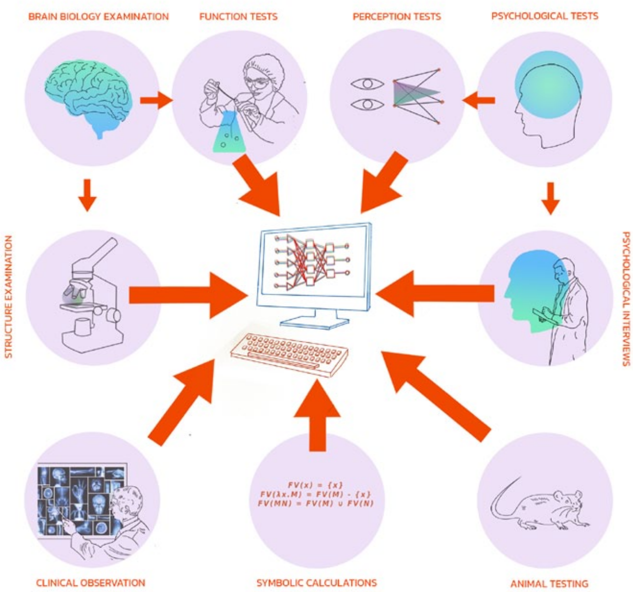



Fig. 1. Sources of knowledge used in the development of artificial intelligence methods

1 – center bottom). The second serious attempt to develop artificial intelligence methods was based on the results of brain analysis (see Figure 1 – upper left corner). Developers of artificial intelligence methods, knowing that human intelligence is born in the brain, imitate the structures and functions of the brain's elements in their algorithms. They do this by creating and utilizing so-called **neural networks**. Another source of knowledge which artificial intelligence is based on is indicated in the top right corner of the figure in question. This source is **psychological research and examination**.

→ **There is no doubt that human mental processes can act as a model for the functioning of artificial intelligence tools. Some of these processes (for example, perception, memorization, and recognition of different patterns) can be studied using specialist apparatus, and others – through interviews.**

Although we are still far from having complete knowledge about the nature and course of the cognitive processes taking place in the human mind, even those fragments of knowledge that have been obtained may be useful in building the so-called **expert systems**.

In the figure in question, we can see also two more sources from which artificial intelligence draws patterns and inspiration: these are animal experiments and clinical observation of patients with various brain dysfunctions. However, these sources will not not be discussed in detail here.

Aware of the complex nature of artificial intelligence, let's try to first characterize it in general terms.

Artificial intelligence is clearly part of computer science even though a large number of computer programs do not utilize artificial intelligence, and some aspects of artificial intelligence, such as **cognitive science** studied by psychologists and philosophers, are not directly related to computer science. The fields of computer science and artificial intelligence thus overlap to a significant degree – but not completely (Figure 2).

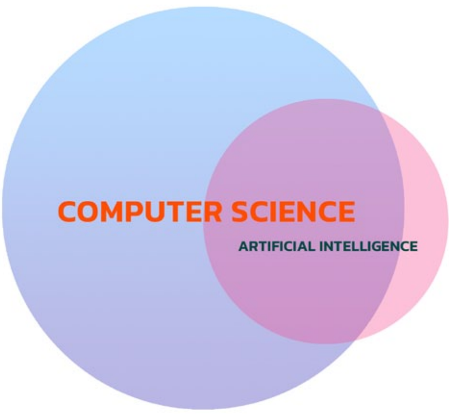



Fig. 2. Relationship between computer science and artificial intelligence

There are many definitions of artificial intelligence. To put it in a nutshell, we can speak of artificial intelligence when a machine (a computer or an electronically controlled device: a robot, an autonomous vehicle, a self-organizing network) manifests behaviors which when observed in humans would make us inclined to consider them a result of their intelligence. In general, AI is developed in two ways (Figure 3).

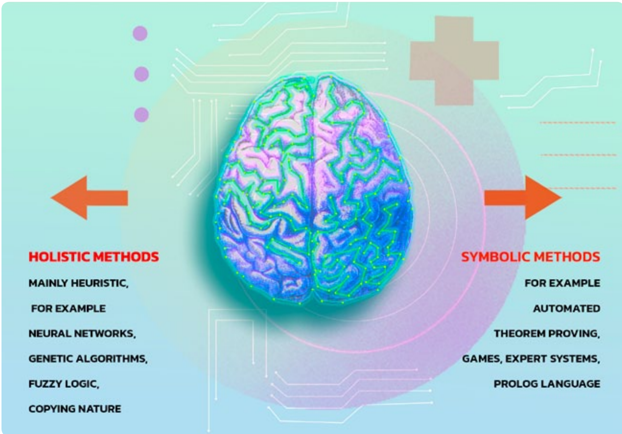



Fig. 3. The most general division of artificial intelligence methods

On the right (Figure 3), there are the so-called **symbolic methods**. The analyzed problem is described and written using symbols, and artificial intelligence algorithms "stir" this set of symbols in such a way that a solution is eventually arrived at – also in symbolic form. This is the traditional – earliest developed but still functioning today – part of artificial intelligence (it will be discussed further). Examples of tasks that were the first to be solved using symbolic methods were programs that automatically proved mathematical theorems and played games (checkers, chess, and now also Go). In the health sector, symbolic methods are made use of by **expert systems**. These are programs which use symbolic methods of automatic inference to answer their users' questions in a similar way as a human expert – i.e. a person with thorough knowledge and wisdom required, for example, to make good diagnoses – would.

However, methods based on the use of logic and operations on symbols fail to achieve all the goals set for AI in the health sector. Therefore, an alternative approach is also adopted. It involves the use of **holistic methods** based on heuristic algorithms. There are various heuristic methods, but the most commonly used are **machine learning** methods where the necessary solution is created on the basis of iterative (i.e. consisting in repeating the same operation a certain number of times or to the expected effect) improvement of a certain preliminary (imperfect) solution. First, these methods include very popular **neural networks**, but other methods in use are also learning decision trees and recognition methods, usually associated with the concept of ***pattern recognition***, richer in content than its Polish equivalent of **image recognition**. Holistic methods include also **genetic algorithms**, which produce the relevant solution as a result of a "solution breeding" process, with the generation of subsequent "generations" of algorithms. Other holistic methods are also **fuzzy logic** and **fuzzy set** theory.

Figure 4 shows a "map" of holistic AI methods. It offers the proposed classification of the abovementioned methods. The size of each area corresponds to the degree to which these methods are used, and the mutual (partial) overlap of these areas corresponds to the relationships existing between these methods.

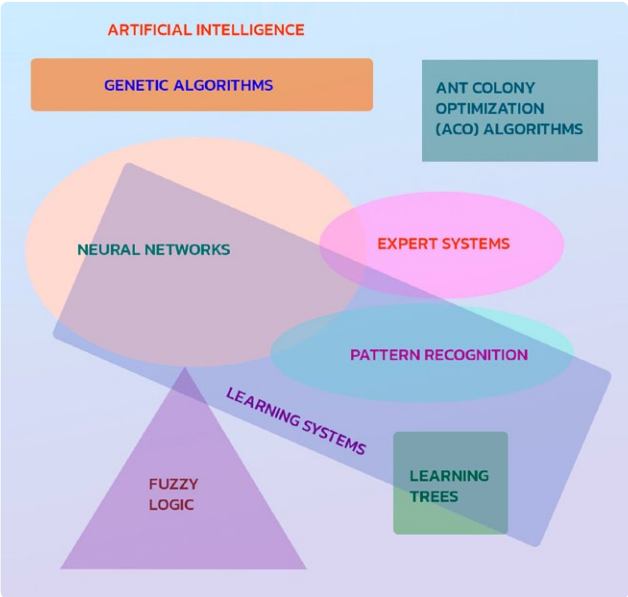



Fig. 4. Map showing different ways of classifying artificial intelligence methods

We can see a large area of **learning systems** coming to the foreground in Figure 4. It needs to be underlined that most of the successful instances of application of AI result from the fact that relevant computer programs can improve their performance and adapt to the user's needs through learning. Such learning systems are **decision trees**. The decision-making process is controlled by a series of conditions (tree branches) that need to be verified for compliance before the next step towards finding a solution is taken. In the case of decision trees, the process of learning is about figuring out what conditions need to be checked, what the order of verification should be, and what the outcome of each decision is. *Pattern recognition* methods involve automatic classification of various objects (images, sounds, ECG signals, patient syndromes, etc.). The classification rules are unknown, but a set of examples of correctly recognized objects is available, and the machine must learn how these correct decisions have been made.

Moving on, we have neural networks (discussed in more detail later in the report) and genetic algorithms – mentioned above. Fuzzy logic, shown at the bottom, involves mapping the smooth transitions between truth and untruth – typical of human reasoning – into the computer. A typical algorithm makes radical distinctions between what is true and what is false. Fuzzy logic makes it possible to effectively use statements that are either partially true or partially false, which brings computer operation closer to human mental processes. The expert systems marked at the top of the figure are programs which combine knowledge gained from experts (humans) with automatic inference methods derived from symbolic artificial intelligence to act as automated advisors to decision-makers.

The last group of the methods covered is the so-called ant colony optimization (ACO) algorithms. They solve problems by mimicking the behaviors of ants, which are able to deal with various issues collectively although no single ant is intelligent on its own. ACO algorithms mimic this collective intelligence.

Due to the nature and the page count limitations of this report, we will only discuss two AI methods below: symbolic calculations and neural networks.

## SYMBOLIC CALCULATIONS

The discovery that computers – initially treated only as computing machines (the very name 'computer' means exactly a computing machine) – could also manipulate symbols was a breakthrough. When it was proven that machines could operate on abstract concepts denoted by symbols as well as on concrete numbers, it was impossible not to acknowledge that a computer was much more than just a fast abacus. Since these symbolic calculations had to be distinguished in some way, the emerging discipline of operating on abstract concepts was given the name "artificial intelligence". It was first used officially at a conference at Dartmouth College in 1956, but the disputes as to who actually coined the term have continued to this day.

It needs to be stressed that the shift in computer technology from numerical calculation to symbolic manipulation was truly of fundamental importance. Numerical calculations are about performing certain actions on specific numbers and getting a specific resultant value – and that is all there is to it. Looking at the following numerical expression:

2 * 3 = 6

we can make use of the result (for example, paying a bill for 2 kg of potatoes, where 1 kilogram is priced at PLN 3.00). But it's hard to try to draw any deeper conclusions here.

On the other hand, looking at the following symbolic expression:

m * a = F

we see one of the most fundamental laws of physics, which lets us draw a range of different conclusions. For instance, we can determine what force (F) the engine of a car of mass (m) should reach in order for this car to travel with the necessary acceleration (a). Or what mass (m) was the sword of an executioner beheading a condemned man (where we need the value of force (F)) when the acceleration (a) that a human hand can reach is limited to a known value. The knowledge of this formula has made it possible for humans to land on the moon and understand what pulse is.

Computers' ability to operate with symbols has paved the way for machine transformation of algebraic formulas, mechanical derivation of the necessary mathematical formulas, and even automatic proof of mathematical theorems. However, when it comes to the health sector, these methods seem less useful so they will not be discussed in more detail here.

## ARTIFICIAL NEURAL NETWORKS

Neural networks are one of AI's creation with a wide range of applications. They are probably the most popular artificial intelligence methods in existence today. When I turned to Google with a query about their use, I received the following results as the response:

Within half a second, the search engine found 129 million (!) documents. This proves that neural networks – as a tool to solve various problems – have been **successfully** used more than a hundred million times. The conclusion that they have been used successfully can be drawn from the following line of reasoning: a book, an article or a paper that Google can find on the internet has been written only by a researcher or practitioner who has achieved some **success** and described it. If someone fails at something – they don't write an article about it or go crying about it at a conference, so the number of such **negative** attempts can't be determined. But the number of successful cases is truly impressive!

The fact that the Google search engine provided an answer in half a second (on the basis of a resource of more than a hundred million documents!) proves that similar questions must have been asked before by a great many of internet users and that the answer obtained as a result of the search must have been ready beforehand. So the number of people posting the query – meaning probably considering how to use neural networks – must be very large. And this is very promising for the further development of this method!

The utility of neural networks in the health sector is documented in e.g. these two voluminous books:


Fig. 5. Illustration of the popularity of neural networks

The essence of a neural network as an AI tool is shown in Figure 7. Neurons are marked as red dots. The blue lines between neurons represent the **synapses** that connect them. It is the changes in these synapses that make up the essence of the networks' learning process, so their state after the learning process represents the **knowledge** that a given network has gained in the process. If we feed the neurons forming the **input** layer with data representing the problem which the network is to currently solve, this knowledge will let the network operate in a way to enable the result being the solution to the problem considered to appear in the **output** layer of the network (in Figure 7, it consists of only one neuron, but it actually often has many neurons when the solution is a vector solution).

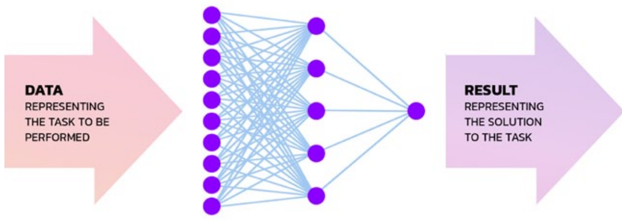



Fig. 6. Books describing applications of neural networks in the health sector

Typical neural networks (especially the most popular ones, **MLP**-type) must be taught by a "teacher" before they are used in practice. The word "teacher" should be treated symbolically here – in a typical situation, it is an iterative computer program which features a knowledge base of **what** to solve (in the sense that the input data and the correct results for example tasks are shown), but has no information about **how** to solve it. The method to arrive at the solution must be created by the network itself, based on **induction**, i.e. moving from detailed examples to a general principle which is not known beforehand. It needs to be added here that the opposite of induction is deduction, which is much more common and consists in knowing some general rule and using it to solve complex and detailed problems.

A neural network capable of induction is a very powerful and useful tool, especially when applied to tasks which we're unable to build algorithms for ourselves – and there are many such tasks in the health sector. Nowadays, very many tasks are solved with the use of so-called **deep learning** networks. They differ from standard neural networks because they have very many layers of neurons (**MLP** networks have up to three of such layers) alternating between *convolution* layers, *pooling* layers, and *subsampling* layers. Such networks learn through unsupervised ("without a teacher") and supervised ("with a teacher") learning methods. These networks have been in use for a relatively short time, but the number of difficult problems they have helped to solve to date is already very large and keeps on growing. It is a phenomenon definitely worth keeping an eye on.

**RYSZARD TADEUSIEWICZ**

*(The author's profile is included in the introduction to the report.)*

# Machine learning – a cross-section of existing solutions

PAWEŁ MORKISZ,
IRENEUSZ WOCHLIK

→ **Artificial intelligence encompasses many independent methods. Here is a brief description of them, accompanied by examples of their use**

→ **The chapter offers an explanation of terms which are useful to the further understanding of AI-related content**

Artificial intelligence methods can be first divided into:
- supervised learning,
- unsupervised learning,
- reinforcement learning.

## SUPERVISED LEARNING

Supervised learning means that there is a data set in the form of a set of **records** for which **the expected results of** the artificial intelligence model (descriptions) **are known**. For example, in the case of the development of a model set to recognize a handwritten digit from an image, the set would be images along with additional information about which digit each image features. The available set of records is usually divided into a training subset and a test subset. The former is used in the model training phase, and the latter makes it possible to verify the model's accuracy and estimate the business value of the model's performance in practice.

It could be visualized in the form of an attempt to teach this task to a human being. In order for a human to learn to recognize written numbers, they need to be shown examples. On the other hand, in order to check whether they have learned to recognize them, it would be necessary to show them images that were not used in the process of learning.

Supervised learning is further divided into two main subcategories:
- classification,
- regression.

**Classification** is a task in which the algorithm is expected to assign an element to one (or more) of the predefined classes. Examples: recognizing numbers and letters from images, recognizing what animal is featured in a given image, diagnosing a disease based on examination results, or recognizing the type of document that has been scanned. Accuracy measures for classification algorithms are mostly defined based on counted values that have been falsely classified. When it comes to medical data in particular, it is important to remember to choose accuracy measures accordingly; the fraction of correctly classified elements alone is often not enough. For instance, in the case of a diagnosis of a rare disease that occurs once in 10,000 people, an algorithm that includes the information that the patient is healthy would demonstrate a 99.99 percent accuracy, but obviously carry no value whatsoever.

An important example of a classification task is image segmentation. It involves assigning a category for each pixel in the image provided as input. This solution finds significant applications in diagnostics, where it enables the detection of various objects in medical images. It is also one of the most important algorithms used in autonomous vehicles – it makes it possible to accurately detect road edges, lanes, other vehicles or pedestrians.

**Regression**, in turn, is a task in which the algorithm should return a numerical value, for example: tomorrow's closing price for a stock, the predicted lifespan of a machine, the predicted sales volume for a drug, or the predicted travel time. Examples from the field of medicine can include estimating the size of a tumor on the basis of the provided imagery.

It is highly important to understand that a specific task can often be changed from classification to regression – and vice versa. For instance, in the case of future stock prices, it is rarely necessary to know the exact prices. The trader usually wants to know whether to buy, hold, or sell their stock. By setting clear criteria for each of these three events, the task for the artificial intelligence model becomes significantly simplified, and the chance for the entire system to work correctly is much higher.

## UNSUPERVISED LEARNING

If there is a large volume of data for which there are no appropriate descriptions (e.g. a large number of medical images without a diagnosis) or the expected results from an artificial intelligence model are not known, it is possible to apply two types of algorithms:

- anomaly detection,
- cluster analysis (or simply clustering).

**→ Anomaly detection algorithms are able to assimilate the standard behavior of a system or data source and then, when dealing with new data, determine that such a situation has not occurred before or that it is highly unusual.**

These algorithms are helpful especially in holistic analysis, where many factors are taken into account (e.g. monitoring of entire industrial systems, joint analysis of many medical results, and analysis of computer or financial network traffic). In a medical context, this might include analyzing all test results at once rather than just looking at individual results separately. These algorithms are also most commonly applied based on a division into training sets and test sets. The difference between these sets is that the result in a test set is validated by a domain subject matter expert, i.e. the algorithm returns the potential information about the anomalies found, and the role of the domain expert is to determine the usefulness of such an algorithm in practice.

Cluster analysis, on the other hand, makes it possible to discover some hidden structures in data, which makes it a solution applied frequently in practice. In particular, it often enables automatic clustering according to seemingly indiscernible common elements. Such automated division lets the analyst focus on similar objects at a later stage, which improves their overall performance. A specific example here would be automated grouping of similar patients or similar types of diseases/conditions in the context of whether the diagnosed tumor is malignant.

## REINFORCEMENT LEARNING

Reinforcement learning is a very different approach, which can be best illustrated using games as an example. When we expect a model to be able to play, say, chess, we do not assume that we can immediately tell if each move is good or bad. The most important thing is to see whether the entire sequence of moves has led to a defeat, a victory, or a draw. A prime example of the success of such algorithms is the game of Go. Until 2015, artificial intelligence would lose to average-level players. Despite the simple rules, the number of the possible strategies to adopt here is much greater than in the case of chess. In Go, each move affects multiple playing pieces (stones) on the board, so the number of all the possible moves that can be made grows extremely fast. The application of the reinforcement learning approach by the DeepMind (Google) team made it possible to deal with this problem. The AlphaGo model they developed won 4:1 against Go grandmaster Lee Sedol in Seoul in March 2016.

Unlike supervised and unsupervised learning methods, reinforcement learning methods are still in an early stage of implementation for solving practical problems. However, it's easy to imagine that it is this category of algorithms that will prevail in the future as it makes it possible to optimize the entire decision-making process rather than just making single decisions. The solution can be potentially applied to optimizing manufacturing processes, running marketing strategies, and managing patient treatment alike.

**PAWEŁ MORKISZ,
IRENEUSZ WOCHLIK**

**Pawel Morkisz, PhD** – PhD in Mathematics, expert in computational methods and deep machine learning, researcher, programmer, manager. He transfers theoretical concepts from computational mathematics into the realm of practical applications supporting solutions based on artificial intelligence. Assistant professor at the Faculty of Applied Mathematics at the AGH University of Science in Technology since 2018. His most significant research results concern the application of artificial intelligence methods to practical problems and numerical approximation of stochastic equations.

As a Deep Learning Algorithms Manager at NVIDIA since 2019, he manages a team responsible for research and development of deep learning methods and their optimization. His main areas of interest are recommendation models and time series analysis. He's been also an ambassador for the NVIDIA Deep Learning Institute for several years now. At present, co-owner of Aigorithmics sp. z o.o., a company implementing projects in the field of artificial intelligence. Previously co-founder and CTO at the tech start-up Reliability Solutions, where he managed a team dealing with data analysis, including predictive maintenance using deep learning, statistical methods, and machine learning. Participant of and speaker at many international scientific conferences, addressing mainly computational methods and artificial intelligence.

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In 1997-2016, assistant professor at the AGH University of Science and Technology, Faculty of Electrical Engineering, Automatics, Computer Science and Biomedical Engineering. Author of over 50 scientific publications, co-author of patent PL224517B1 "System for recording and processing of signals for the diagnostics of hearing system and method of recording and processing of signals for the diagnostics of hearing system".

One of Poland's first entrepreneurs creating professional, fully medically certified (according to ISO 13485 standard) solutions making use of ICT and AI technologies in telemedicine projects. Involved in data analytics and creating intelligent solutions for business for over 20 years. He specializes in digital transformation and advanced data analytics. Speaker at scientific and business conferences.

Example of application

# Automatic speech recording

Tomasz Jaworski

## → Voice recognition systems are one of the primary applications of AI in healthcare

Automatic speech recording is a term used to describe the various applications of NEWTON Dictate software designed for transcribing speech to text. In medicine, this software is used in the process of drawing up of examination reports (including subject examinations), completing medical records, and describing samples.

The program features specialized dictionaries containing specific vocabulary used in various medical specialties, e.g. in radiology or histopathology.

The NEWTON Dictate software is used at the Pathology Department of the hospital in Hradec Králové, where up to 2,000 laboratory tests are performed every day. Physicians dictate their findings, which must be recorded and uploaded to the computer system as soon as possible. This means a heavy workload for everyone involved. After the introduction of NEWTON Dictate, not only did the efficiency of the physicians' operations increase significantly, but also the number of errors decreased compared to the number of errors made in manual transcriptions.

Doctors use the latest Philips SpeechAir digital voice recorders to dictate examination results, after which the recordings are automatically downloaded and NEWTON Dictate converts the recorded speech to text. This text is then transferred to the laboratory computer system. The only thing left to do is a final check. "Most of the corrections are only trivial errors or substitutions, because the automatic transcription is very accurate thanks to the specialized dictionary," says Prof. MUDr. Ales Ryska[1].

### EASY VICTORY

Voice recognition systems are one of the most consistently applied AI-based solutions in healthcare. Many studies show that the use of speech recognition in medicine translates into a significant increase in the level of both patient and medical staff satisfaction, documentation quality, and process efficiency. Better working conditions offered to physicians and medical staff go hand in hand with:

- 81% lower costs of creating health records;
- adoption of the process and standards of creating electronic health records (EHR) at the level of 77% (compared to 20% when making entries to EHR manually);
- 74% of acceptance rate for automatic speech transcription solutions (Microsoft's own data from customer satisfaction surveys).

NEWTON Dictate takes into account the specific inflection of the Slavic languages, which is why it has been highly successful in the Czech Republic (Pathology Department of the hospital in Hradec Králové, Thomayerova Nemocnice Hospital in Prague, and more than 30 other hospitals), Croatia (Klinički Bolnički Centar and Poliklinika Sveti Rok in Zagreb), Slovakia (private Pro Diagnostic Group and the F.D. Roosevelt University Hospital in Banská Bystrica), as well as with one of Poland's leading private healthcare providers (LUX MED Group).

## PAPER-FREE

Healthcare is somewhat lagging behind banking, telecommunications or e-commerce when it comes to implementing AI solutions. Meanwhile, some of the solutions from other industries, applied in the domain of debureaucratization and transition to a more convenient form of documentation, can bring many significant advantages if they are implemented on a large scale. Such solutions include not only speech-to-text transcription, but also a more widespread adoption of voice and multichannel/omnichannel communication, as well as making use of digital identity and electronic signatures.

The NEWTON Dictate solutions enabling automatic transcription of speech to text can be successfully applied in "shorthand" typing of the content of online/phone consultations, which could prevent very important parts of records concerning the interaction between the doctor and the patient becoming lost. Today, due to the lack of mechanisms that would be accepted in the online/phone medical consultation system, the above is a very common problem. Thanks to the application of speech-to-text transcription, the course of an online/phone medical consultation could not only be properly documented, but the information could also be easily indexed and browsed in the relevant medical/insurance systems. On the other hand, once a "note" documenting the course of an online/phone consultation is drawn up automatically, it could be almost immediately presented to the doctor, the patient, or the insurance/service payer in the form of electronic documents. It would also be possible to add an electronic signature to such records, which would offer an additional layer of security to everyone using these solutions in emergency situations or circumstances involving a high risk of civil or criminal liability.

TOMASZ JAWORSKI

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# Chapter II.

# Implementing AI in the health sector

JAROSŁAW BUŁKA,
PAWEŁ MORKISZ,
IRENEUSZ WOCHLIK

The term "health sector" covers a variety of areas and business models that provide services related to prevention, diagnostics, therapy, rehabilitation, research and development of new drugs and therapies, or public health in a broad sense. These models are often characterized by complex legislative requirements, distinct ethical guidelines, and varying levels of risk involved in implementing solutions based on artificial intelligence algorithms.

This extremely vast area, consisting of many fields, encompasses issues concerning economics and management in healthcare, effective creation of development strategies of entities providing the abovementioned services, financial macroanalysis of specific medical procedures, and public health alike. This last aspect is especially interesting from the point of view of the implementation of AI algorithms because these technologies provide highly effective tools to create and analyze multidimensional maps of health needs as well as model the dynamics or prediction of disease incidence.

The implementation of AI in diagnostics is a separate matter, of great importance to the improvement of its quality as well as to the acceleration of its overall development. It is precisely in the field of medical diagnostics where we can most often see how artificial intelligence spectacularly supports doctors in making diagnostic decisions or in therapeutic processes, how it offers a completely new quality in personalized medicine, and how it supports advanced clinical trials and the development of new drugs.

The very technology referred to as artificial intelligence will be highly similar, and in many cases even the same, but the goals set for it will be different – and the ways to achieve them will largely depend on the areas in which these solutions will be implemented.

## SELECTED AREAS IN THE HEALTH SECTOR AND THE EASE OF IMPLEMENTATION OF AI-BASED SOLUTIONS

**The area of management** in healthcare, considered both at the national level and at the level of a single medical facility, offers a wide range of opportunities to implement solutions utilizing artificial. In formal areas, it does not differ from the requirements set for such implementations in other sectors of the economy. This area makes it possible to apply predictive analytics and optimization models to make better decisions. Classical regression models, classification models, and reinforcement learning models can be used in this context.

**Public health** is an area which is more sensitive to the effects of adoption and application of solutions based on artificial intelligence. The use of recommendations or predictions created by artificial intelligence algorithms, e.g. to create maps of health needs or to model the dynamics of epidemics or chronic diseases, can have a significant impact on strategic decisions at the national level. This will translate directly into the readiness of the health sector to provide proper medical care to the country's citizens.

Thinking ahead, the errors generated by artificial intelligence can indirectly affect the ability to provide a particular person with the right medical procedures to best protect their health and life. Considering the vast possibilities that artificial intelligence offers us, we must not forget that ill-prepared data, mismatched algorithms, or improperly generated models can pose certain risks.

→ ***Federated learning*, i.e. a new trend that makes it possible to protect data as necessary by training models in a distributed (decentralized) manner without the need to transmit and aggregate all sensitive data, and by only transmitting weight updates in an encrypted form, may prove important for this sector.**

**Diagnostics** is one of the most challenging areas related to making decisions directly concerning patients – and to the consequences of such decisions. Artificial intelligence algorithms can be implemented directly in medical devices as well as in software used to support doctors in the diagnostic process. Whether we are dealing with a piece of equipment or software that generates information used in making diagnostic decisions, we are dealing with medical devices. Medical devices are subject to a specific classification system. This classification imposes further requirements that must be met before a solution can be deployed for widespread use. Artificial intelligence in medical devices is a relatively new phenomenon in the field of legislation and certification, so the emerging guidelines and specific requirements related to this field should be followed with particular attention. However, the adoption of such solutions seems to be a very natural course of development – the currently developed methods of segmentation or classification boast an accuracy and speed incomparably greater than any analyses performed manually by doctors or diagnosticians (for example, models detecting early stages of skin cancer on the basis of images taken with mobile phones).

**Therapeutic processes and personalized medicine** involve making decisions regarding particular measures and using certain drugs at specific doses and times when taking care of a given patient. Here, again, the recommendations generated by artificial intelligence have to do with direct actions taken to benefit the patient. This involves appropriate classification of such solutions in the range of medical devices and the adoption of the right approach to the process of marketing such solutions. The application of artificial intelligence models allows this process to be fully customized by using models with a large number of parameters. They can absorb multiple degrees of freedom and have the ability to generalize to come up with appropriate recommendations for new patients.

**The development of new drugs** with the use of artificial intelligence solutions is a relatively new area, but one with great potential – and some tangible examples of success already. In recent months, a drug based on a new molecule developed by artificial intelligence has entered clinical trials. It took AI algorithms a year to select the right ingredients to create it. It is estimated that the process would have taken five times longer if the traditional testing procedure had been applied. This is an example that proves the potential of artificial intelligence and shows clearly how it starts to affect the health sector. The process of creating new drugs itself is strictly regulated, and artificial intelligence fit perfectly into the early stages of R&D and designed a new molecule in a time frame not achievable with previous research approaches.

**The technological aspects** related to the process of implementing artificial intelligence in the health sector in recent times have ceased to be a barrier and a big challenge for institutions or companies wishing to make use of this technology. The increasingly popular public cloud and its dynamic advancement in the area of tools and platforms supporting artificial intelligence solutions means that initiating the process of design and development of solutions based on AI algorithms does not involve a long waiting time or significant investments anymore.

**The process of implementation of AI solutions in the health sector**, apart from the abovementioned specific circumstances, will be similar to the implementation of this type of solutions in other areas of the economy. In order to minimize the risks and errors involved in the selection of the issues set to be supported by artificial intelligence, it is a good idea to divide the implementation process into stages that will make it possible to monitor the implementation. Below is an example of the stages and issues suggested to be considered.

**Strategy** – once a decision has been made to implement solutions based on artificial intelligence, it is important to draw up a strategy on how such solutions will be incorporated into the intended organization and what organizational activities should be performed to make such implementations easily adaptable to everyday work. At this stage, it is also reasonable to choose the environment in which the implementation is to take place and the target model of implementation of such solutions (e.g. hybrid cloud, public cloud). A strategy for implementing AI solutions should also involve the appointment of an AI accountability specialist (team of specialists).

**Workshops** – are an excellent tool to choose specific areas in a given organization, which can bring added value when supported by artificial intelligence solutions. An analysis of the mechanisms and processes adopted in one's organization as well as the organization's activity, needs, and potential makes it possible to consciously select those areas where the utilization of artificial intelligence can be of particular value.

**Analysis** – this is an extremely important process, especially when dealing with the health sector. A feasibility study should be prepared at this stage, taking into account the relevant technological and legal aspects as well as a risk assessment. Before proceeding with technological implementation, it is necessary to consider e.g. the legal possibilities to use data, license verification, certification classification (if applicable), patent purity and the business value of the solution, as well as success criteria (minimum accuracy of algorithms, maximum system latency, etc.).

**Implementation** – at this stage, apart from the technological implementation itself, the most important elements are application and database licenses, implementation agreements, cloud services agreements, insurance, Public Procurement Law (in the case of the institutions concerned).

**Maintenance** – this stage, in addition to the purely technical aspects such as maintaining AI models and environment, monitoring their quality, and managing the training process, should also include monitoring for changes in the law related to this particular application. This is all the more crucial because issues related to law, ethics, and human rights in the field of artificial intelligence are currently being thoroughly analyzed and debated on at both the level European Union level and across individual Member States.

## CONCLUSIONS

Implementing AI in the health sector in many areas requires more attention and caution than in the case of other sectors of the economy. As mentioned earlier, the technology itself and the possibilities of its implementation do not differ much from the most common trends. However, the field we are dealing with requires a broader perspective and involves a close monitoring of additional legislative and certification aspects. However, this fact should not discourage us from taking advantage of what artificial intelligence offers now and will offer in the near future. It's a field that has taken virtually every sphere of our lives by storm, and excluding the health sector from the revolution it has brought about would be a huge mistake – especially since we can already see the huge potential and the great results of the practical application of AI-based tools.

The dynamics of AI development in the world as well as the constantly emerging new guidelines and regulations may cause the enthusiasm to adopt this technology to cool down. As the subject of implementing artificial intelligence solutions in the health sector is multidimensional, in a situation where a given entity does not have the necessary human skills to create safe standards for AI solutions, there is always a chance to turn to organizations that have specialists qualified to handle all the areas mentioned above among their ranks. Such support can accelerate the process of effective utilization of artificial intelligence solutions and building of knowledge in this area within the organization.

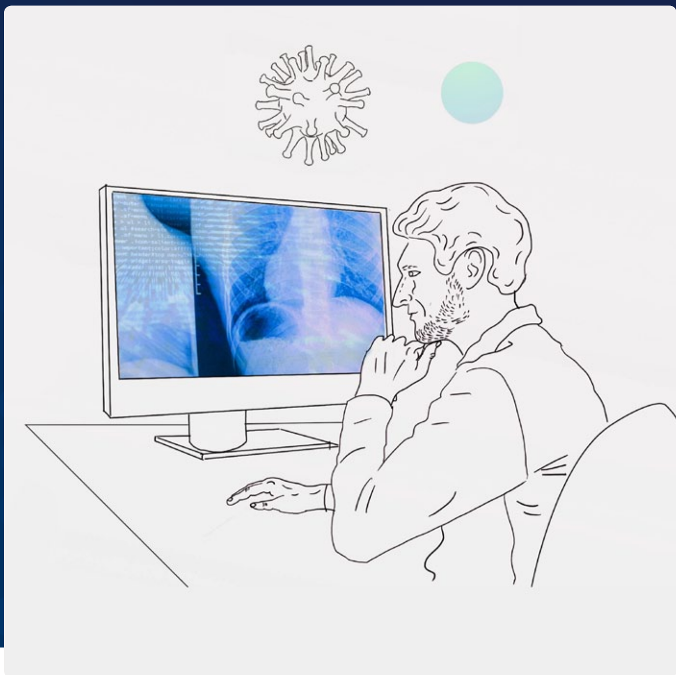
**JAROSŁAW BUŁKA,**
**PAWEŁ MORKISZ,**
**IRENEUSZ WOCHLIK**

*(Paweł Morkisz's and Ireneusz Wochlik's profiles are included in Chapter I.)*

**Jarosław Bułka, PhD, Eng.** – a biocyberneticist with 20 years of academic experience gained at the Department of Automation and Biomedical Engineering at the AGH University of Science in Technology. Author of more than 50 publications in the areas of AI, neural networks, telemedicine, remote diagnostics, and biomedical engineering. Co-organizer of industry conferences, panelist, and popularizer of R&D and transfer of knowledge from science to business. Since 2002 Secretary of the Accreditation Commission of Universities of Technology; technology expert for the Association of Polish Counties and Kraków Technology Park. Member of the Małopolska Innovation Council, of the Information Society Council at the Marshal of the Małopolska Region, and of the Scientific Council of the Małopolska Centre for Translational Medicine, plenipotentiary of the Mayor of Krakow for Digital Transformation. Until 2018, Director of the New Technologies Department of the National Institute of Senior Economy and Member of the Board of the LifeScience Krakow Cluster Foundation. Organizer and executor of many innovative R&D projects. One of Poland's first entrepreneurs creating professional, fully medically certified (according to ISO 13485 standard) solutions making use of ICT and AI technologies in telemedicine projects. Currently co-owner and CEO of MedDataSolution.

# Artificial intelligence in radiology

PRZEMYSŁAW CZUMA



→ **Artificial intelligence is used in medical image analysis and diagnostic support**

→ **Intensive research work is accompanied by a growing number of proposals of commercial application of AI**

**"If you work as a radiologist, you're like the coyote that's already over the edge of the cliff, but hasn't yet looked down so doesn't realise there's no ground underneath him. (...) People should stop training radiologists now".**

These controversial words, which reverberated in circles not only directly involved with healthcare, were spoken in 2016 by Geoffrey Hinton[1], a specialist considered one of the "godfathers" of machine learning (even though, strictly speaking, the term "artificial intelligence" has a slightly broader meaning than "machine learning", in the following paper, these two terms will be used interchangeably for clarity).

## A GREAT LEAP

Have Hinton's provocative claims actually become reality? Or are they just yet another example of excessive optimism, seen so frequently in the history of *artificial intelligence* (AI) and having proven so many times to be unfounded?

There's no doubt that the last decade has seen a rapid development of AI in many – often very distant – fields. It is considered to be the main driving force behind the Fourth Industrial Revolution[2]. Medicine in its broadest sense is one of the spheres in which this development is particularly turbulent.

With *deep learning* (DL), a category of machine learning that uses neural networks, the field where the advancement of AI advances is particularly pronounced is *computer vision*.

→ **It is no coincidence that radiology, as a discipline based largely on the interpretation of digital images of the human body, is among the areas boasting some of the most advanced medical applications of AI algorithms.**

The claim regarding the dynamic development of AI in radiology is clearly proven to be true by e.g. the almost exponential increase in the number of scientific publications in recent years (Figure 1).

## ALGORITHMS IN CLINICAL PRACTICE

The intensified research efforts go hand in hand with an increasing number of proposals for commercial application

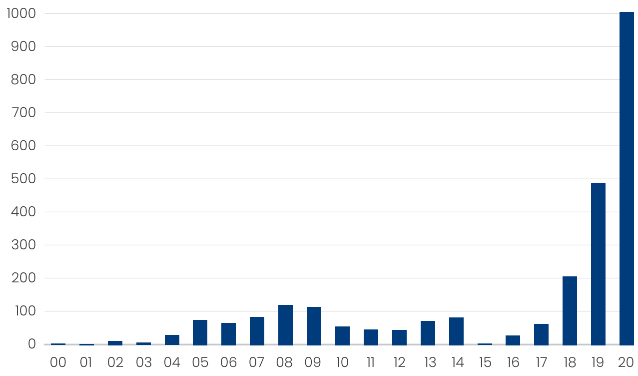



Fig. 1. Number of scientific publications containing the words *radiology* and *artificial intelligence* from 2000 to 2020 (Source: medpub.gov)

of AI – which is arguably an even more sensitive indicator of AI's potential utility in clinical practice. And so, the first commercial AI algorithm was approved for clinical use by the U.S. Food & Drug Administration (FDA) in 2016[3]. To date, several dozen such solutions have been registered, with the vast majority of them focuses on imaging methods used in radiology and cardiology (Figure 2).

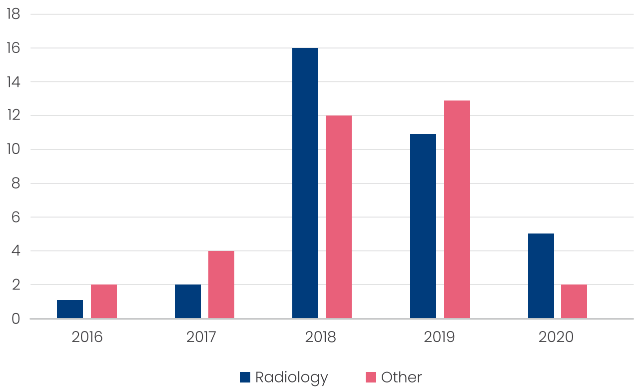



Fig. 2. Number of AI tools approved by FDA by year (source: medicalfuturist.com)

Although it is outside the scope of this paper, it may be reasonable to mention here the new regulatory challenges legislators have to face. More and more algorithms are "adaptive", i.e. modifiable (meaning: improvable) based on data they are fed during their use. Therefore, in contrast to the "analogue" diagnostic instruments used so far, their effectiveness cannot be treated as a static value, one given "once and for all".

An overview of instances of application of AI in radiology which been given FDA's approval illustrates well both the direction of evolution and the spectrum of these methods. It also makes it possible to adopt a certain classification.

The simplest and most obvious divisions take into account the type of radiological examination to be assisted by AI: radiography (X-ray), computed tomography (CT), magnetic resonance (MR), ultrasound (US) – and/or the body region/organ being examined (head and neck, chest, heart, abdomen, etc.).

## FIVE LEVELS OF AUTONOMY

A slightly different – interesting – approach to the issue is a classification inspired by the "autonomy" assessment of self-driving cars (autonomous vehicles)[4]:

**Level 0** are systems that process images but do not have diagnostic support capabilities. Their primary purpose is to improve the quality of data provided to the radiologist, which increases the chances for a quick and accurate interpretation.

An additional significant advantage of this type of solutions is the reduced duration of examination time and the resultant decrease in patient exposure to potentially harmful factors (ionizing radiation, contrast agents). Such solutions include e.g. the 2019 FDA-registered Advanced intelligent Clear-IQ Engine (AiCE), which improves resolution and reduces noise in CT and MRI images.

**Level 1** talgorithms aim to identify one specific anomaly, from femur or wrist fractures (OsteoDetect) through artificial pneumothorax (HealthPNX) to cerebral stroke (ContaCT).

AI-based software developed by a Polish company named Brainscan makes it possible to detect different types of intracranial bleeding – with very high accuracy.

The application of this type of solutions in situations that require quick initiation of treatment, e.g. in the case of victims of traffic accidents, seems to be particularly promising. Their role would be mainly to shorten the time from examination to result, including by informing the radiologist – even before the examination is finished – that they may be dealing with a potentially life-threatening condition.

The COVID-19 pandemic has proven to be an extremely powerful stimulus for the development of AI-based instruments for the early detection of pulmonary lesions in SARS-CoV-2 infection. At least a dozen such instruments have been developed in different parts of the world. These include the domestic Circa system, created by specialists from the Silesian University of Technology[5].

**Level 2** includes more sophisticated algorithms, capable of recognizing not one but many different pathological changes within one or more organs. A commercial example of such a solution is the Icobrain software developed by the Belgian company Icometrix. It makes it possible to diagnose and assess the severity of a number of neurological disorders such as multiple sclerosis, dementia syndromes, epilepsy, strokes. An interesting – and completely free – tool from this group is Chester6 – "the AI Radiology Assistant" (named after the word chest). It enables a comprehensive evaluation of a chest X-ray – the most frequently performed radiological examination in the world – from the level of a web browser, taking into account as many as fourteen parameters (Fig. 3).

**Levels 3 and 4** are software with skills at and exceeding those of a trained radiologist, respectively.

For now, Geoffrey Hinton's bold claims from five years ago are closer to futurism and *science fiction* than to what the near future holds. Especially if we consider that the level of complexity of a radiologist's work far exceeds "pattern identification" or "image description". Something that would seem simpler, i.e. a correct performance of abdominal ultrasound, remains beyond the reach of the most advanced robotic systems.

Of course, it is difficult not to see that the abovementioned division is very general.

## MORE POSSIBILITIES

The possibilities of utilizing AI in radiological image classification are much broader than more or less autonomous diagnostics. Digital image processing supported by AI makes instant quantitative analysis – beyond the potential of human senses and mind – possible.

→ **The abovementioned Icobrain system makes it possible to detect even subtle brain volume losses in the early phase of Alzheimer's disease or to objectively quantify the development of multiple sclerosis on the basis of CT examination.**

There are AI-based tools that already outperform their human counterparts when it comes to assessing the risk of developing cancer based on mammography results[7].

Many hospitals in India, a country with one of the highest prevalence rates of COVID-19, use qXR software, which is not only a screening test that instantly detects the disease based on X-rays but also tracks its progress in an automated manner[8]. What's more, qXR can identify high-risk patients at risk of severe infection, allowing them to receive appropriate medical care before their condition deteriorates[9].

Before the pandemic, the qXR algorithm served as a tool for detecting tuberculosis – it is estimated that its use reduced the cost of diagnosing the disease by 45-55 percent.

Let's return briefly to the 'case' of Chester, the free "radiology assistant" that has become quite popular, to look at some interesting aspects of making such instruments available *online*.

Chester is able to offer a preliminary, quite "expert" assessment of a chest X-ray result without the involvement of a human radiologist. At a time of worldwide shortages of health professionals, such a solution could improve patient care, particularly where shortages are most acute (e.g. developing countries) – but not only there.

## DOCTOR VS AI

Most certainly, in places with good access to medical care there will also be patients who will want to confront the radiologist's description with what the algorithm's analysis will show. On the one hand, detecting possible human omissions will increase the chance of appropriate treatment, but on the other hand, in some situations, it may become a source of disputes – including legal ones.

There are several scenarios of the "human doctor versus AI" conflict, which inevitably lead to the "black box" issue, i.e. a situation where even the creators of an algorithm find it difficult to explain why the algorithm produces particular results. However, this is too vast a topic to be even briefly addressed in this paper.

Of course, a radiologist does not only interpret the obtained images. This activity, although of crucial importance, takes only about 50% of their work time[10]. The remaining part of their work involves equally important tasks: selecting and preparing patients, choosing and conducting an appropriate examination procedures, describing results and communicating them to patients, as well as research and scientific activity.

Each of these tasks can be facilitated with the help of AI, making radiologists' work more effective and increasing the possible amount of time they can spend analyzing results.

Since most of these types of AI applications are less specific to radiology, they will only be mentioned briefly.

The use of deep learning helps in e.g. deciding whether it is necessary to apply a contrast agent during an MRI scan[11,12].

Solutions using speech synthesis and natural language processing (NLP), which are offered in Poland by e.g. Techmo, can be used to streamline patient registration through the utilization of voicebots, help automate the description of tests, and facilitate browsing of databases for statistical and research purposes.

## AN ALGORITHM CANNOT REPLACE A RADIOLOGIST

The examples of application of AI in radiology discussed above are only a small fraction of a larger whole. New reports of utilization of machine learning in this field make it to the public almost day after day.

Does this really mean that the days of radiologists are numbered? Is Geoffrey Hinton right in arguing that physicians

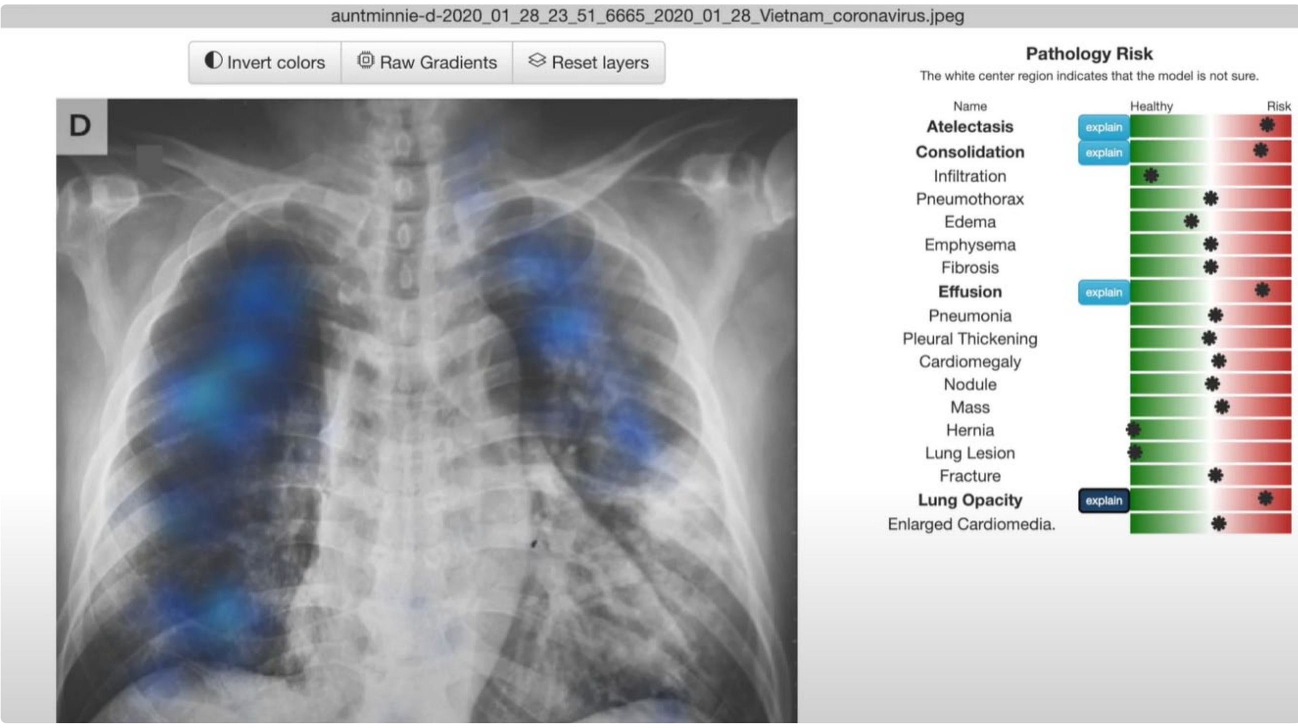


Fig. 3. Chester user interface (source: https://mlmed.org/)

in this specialty are like coyotes over a precipice, about to disappear from the horizon of medicine with artificial intelligence pushing them off the edge[13]?

Curtis P. Langlotz, a Stanford University radiologist, aptly dispelled those fears: "Will AI replace radiologists?" is the wrong question. The right answer is: Radiologists who use AI will replace radiologists who don't[14].

The author of this text fully shares this view. In the near-to-medium term, artificial intelligence will make working with medical imaging much more efficient – radiologists, the vanguard of medical applications of machine learning, will become not "Wile E. Coyotes" but true "Road Runners of healthcare".

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**Lek. med. Przemysław Czuma** – surgeon-practitioner, specialist in orthopedics and traumatology dealing with e.g. joint endoprosthetics with the use of the latest implantology achievements and reconstruction of the complex mechanism of the human foot; creator of a minimally invasive method of femoral stabilization. Active participant and speaker at many medical conferences and events dealing with implementation of new technologies with special focus on medical application of artificial intelligence. Originator and organizer of the newly established Polish Association "Artificial Intelligence in Medicine" – a platform that brings together various environments interested in the development of medical AI in Poland (www: inteligencja.org.pl). Futurist, great fan of Stanisław Lem's writing, and moderate supporter of the hypothesis of simulation – he addressed these topics in "Filozofuj!" – a Polish nationwide philosophical periodical.

Example of application

## Non-invasive diagnostics of the brain

Tomasz Jaworski

### → A highly sophisticated neural network specialized and designed for FCD detection and segmentation has been developed

Even some minor changes in the structure of nervous tissue can translate into very serious consequences for people's lives. One such consequence is focal cortical dysplasia (FCD), a defect in the structure of nervous tissue and in the maturation of cells within the cerebral cortex, which is a common cause of drug-resistant epilepsy in children and adults. There are several subtypes of FCD. All forms of focal cortical dysplasia are believed to manifest themselves as abnormalities in neuronal structure, such as dysmorphia and the presence of "balloon" cells – cells that exhibit features of both glial and neural cells.

The Hamburg Epilepsy Centre has the largest monitoring station for comprehensive epilepsy diagnostics in Germany. The facility is one of the most important centers for the detection and treatment of epilepsy in Europe.

In the case of FCD, the lesional areas may vary in location, size, and shape, and are usually blended into the surrounding tissues without clear, defined boundaries. Detecting them is also very difficult for physicians, and reliable detection of FCD involves expert judgment of an experienced epileptologist. This makes many FCDs – as sources of epilepsy – remain undetected. Meanwhile, detected FCDs can be operated and the patient doesn't have to suffer from epileptic seizures.

### NEURAL NETWORK FOR FCD DETECTION

Experts from the Epilepsy Hamburg Centre, together with their partner, Microsoft theBlueAI, decided to use the power of artificial intelligence to automatically detect and recognize the location of FCDs in medical images. A highly sophisticated neural network specialized and designed for FCD detection and segmentation has been developed. It is more sensitive and accurate in detecting FCD than any conventional visual analysis.

In February 2021, a scientific paper summarizing the research team's achievements was published in the prestigious specialist medical journal Epilepsy Research[1]. Experts consider the developed model to be useful for screening for FCD in clinical practice. The use of artificial intelligence makes it possible to examine and diagnose more patients and enables the standardization of screening tests as AI becomes more and more accurate with each image analyzed. According to the recommendations of the European Union ("Ethics Guidelines for Trustworthy Artificial Intelligence"[2]), the solution developed is only to support the autonomous decisions of the physician, to enable authorized personnel to exercise complete supervision, and – in particular – to enable the analysis of the source diagnostic images acquired from MRI.

However, it would not be possible to achieve impressive screening results without the use of automated sample analysis – supervised by a physician. As proven in the abovementioned scientific paper1, the accuracy of the initial diagnosis cannot be overestimated. A preliminary diagnosis does not preclude further testing; in fact, this is a standard practice in neurological diagnostics. Considering the disparity between the growing needs of patients and the number of qualified medical specialists, it should be concluded that the additional tool in the form of artificial intelligence has a significant impact on public health, the safety of patients with epilepsy, and the overall comfort of their families.

### CHALLENGES

Diagnosing FCD is a much more complex task than many other tasks AI is utilized in – for example, in radiology, where it is used for brain tissue segmentation or tumor detection. A big challenge when it comes to AI applications results from the fact that FCDs vary widely in location, size, and shape, while mostly blending into the surrounding tissue without forming clear, definable boundaries. MRI analysis carried out by experts is time consuming, requires expertise, and – in some cases – tends to be subjective. This makes it difficult to compile a set of reliable data to train artificial intelligence.

**→ Thanks to the extensive technological research and efforts of doctors from the Hamburg Epilepsy Centre, it was possible to create the largest MRI dataset of FCD diagnostic images collected to date – and achieve high scores in FCD detection.**

The detection of focal cortical dysplasia is the most advanced example of the use of multiple technologies developed by TheBlueAI. Solutions designed by Blue Diagnostics[3], such as segmentation and detection, are also incorporated and used directly in another versatile solution: VSI Holomedicine. It is used to identify and visually segment a variety of anatomical structures, such as:

- visual bone segmentation;
- renal calyces;
- detection and segmentation of brain tumors;
- segmentation of blood vessels;
- the brain (white matter, gray matter, cerebrospinal fluid);
- complex neuropathology detection and segmentation.

VSI Holomedicine i zastosowania sztucznej inteligencji wspierają lekarzy, zwiększają bezpieczeństwo pacjentów, zmniejszają ilość żmudnej pracy ręcznej diagnostów, oszczędzają zasoby, pozwalają odzyskać czas na ważniejsze zadania i zapewniają szybką ocenę stanu zdrowia pacjenta dzięki zautomatyzowanym procesom.

**TOMASZ JAWORSKI**

*(The author's profile is included in Chapter I.)*

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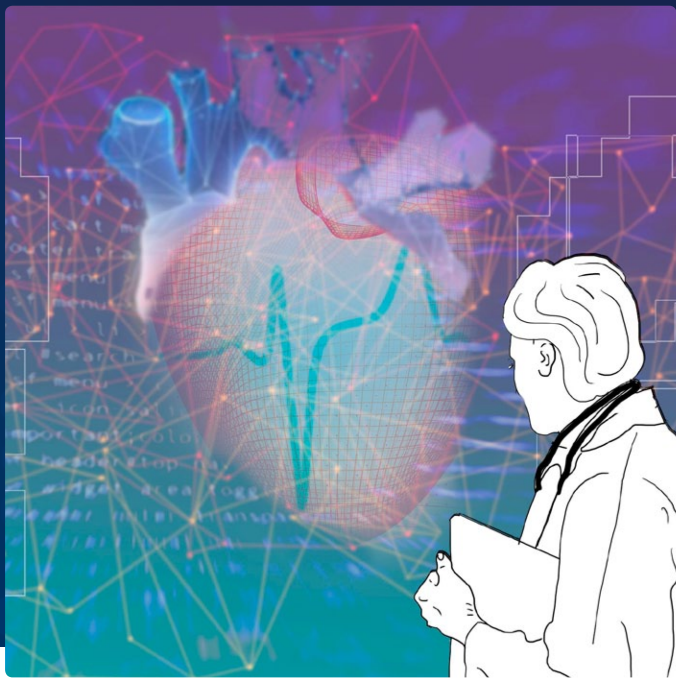
3. Blue Diagnostics (full name: Blue Healthcare Diagnostics) is a platform with a range of various tools and solutions making use of artificial intelligence in the area of healthcare.

# Artificial intelligencje in cardiology

MAREK TOMALA



→ **Artificial intelligence in cardiology is used in two main domains: computer-based and physical (robotic)**

→ **Cognitive computing has been applied in e.g. medical image analysis, machine learning, and automated clinical decision support systems**

At present, diagnosing cardiovascular diseases is based on the analysis of available medical records, imaging, biomarker results, and physical examination of individual patients, which are interpreted in accordance with the cardiologist's personal experience. Each individual clinical case is matched up to a traditional taxonomy of conditions and then subjectively interpreted based on relevant medical literature and referred for treatment recommended in the guidelines for a specific group of patients. It is more and more common to see such procedures turning out to be inefficient and error-prone, difficult to adapt to the treatment of atypical patients, and limiting the personalization of therapy. At the same time, improving the efficiency of physicians and healthcare systems is becoming increasingly important. The response to technological advances is the increasing demands of patients, who expect greater availability of more personalized and individually tailored care (individual treatment – IT)[1]. Each and every day, physicians interpret growing amounts of more and more complex data. This is accompanied by expectations of the system to be more efficient, which results in a progressive limitation in access to appropriate specialist care. Accurate analysis of medical images, such as computed tomography, and their urgent interpretation is often a must in emergency departments in facilities with different referral levels, often without access to specialist consultants.

A potential solution to these problems is the adoption of machine learning (ML), which can improve every step of patient care – from history taking through diagnosis to treatment selection. As a result, the use of artificial intelligence (AI) can make clinical practice more efficient, convenient, universally accessible, and personalized. In addition, it will be possible to make use of cloud storage of resources in the future2. Such solutions will become a combination of a stream of biomedical data, collected on the fly and automatically delivered by mobile sensors, smartphones, etc., and information resources collected by the healthcare system in the current form.

## AI IN CARDIOLOGY: TWO TRENDS

Artificial intelligence in cardiology is used in two main domains: computer-based and physical (robotic)[3]. Cognitive computing makes it possible to improve the control of healthcare management systems, i.e. electronic medical records (EMR). It is also used in software for medical image analysis such as angiography, echocardiography, computed tomography, cardiac magnetic resonance, intravascular ultrasound, and in machine learning, deep leaning (DL), natural language processing (NLP), and automated clinical decision support systems[4].

When it comes to robotic arms, machines performing percutaneous coronary artery interventions (*robotic assisted* PCI – R-PCI), such as CorPath 200 or Robocath System[5], have been used in interventional cardiology at the stage of clinical implementation. They can be used to perform even highly advanced percutaneous coronary artery procedures. The interventional cardiologist who controls the device that directly performs the procedure can be in a separate room and doesn't have to wear heavy protective clothing, protected against exposure to radiation or orthopedic trauma. The da Vinci robot is used very commonly. It has made it possible to perform cardiac surgical procedures of coronary artery bypass grafting and mitral valve repair[6].

## AI AND ML VERSUS STATISTICAL RESEARCH

Inference based on statistical methods – used in cardiology – is being increasingly replaced by artificial intelligence algorithms. Machine learning identifies features and qualities on the basis of data, makes predictions, and provides tools and algorithms to understand patterns obtained from large, complex, and heterogeneous data sets.

Additionally, ML algorithms rely on fewer assumptions and can provide better and more robust predictions in some cases. An example can be the attempt to predict the likelihood of readmission to hospital for an exacerbation of CHF within 30 days of discharge. AI enables the use of an extensive but unstructured dataset of electronic medical records covering various variables such as International Classification of Diseases (ICD) billing codes, drug prescriptions, lab results, imaging studies, and visit notes. It is difficult to decide in advance which ones should be included in the predictive model. Traditionally, regression-based statistical methods are limited by their ability to use a limited number of predictors that have the same effect on all variables with homogeneity across their entire range. Choosing the right logistic regression model is actually algebraically impossible when there are more independent variables than observations because it is not possible to create a function that would describe such a relationship. Furthermore, the interactions between the considered factors – which take place in physiological processes – may be too complex to be captured by the most common regression techniques. An example here can be the creation of an algorithm making it possible to determine which patients with cardiogenic shock could benefit from mechanical circulatory support. In such a case, it is very difficult to classify the quantity and quality of interactions that occur simultaneously and undergo dynamic changes using traditional methods. With ML, it is possible to create an algorithm that utilizes these complex relationships occurring over time[7].

The idea behind the use of generalized boosted regression (ML approach) is that the algorithm corrects its previous errors in each successive step and an attempt is made to match the new – improved – predictor with the residual error made in the previous cycle (validation) after each run. The gradient boosting method based on this algorithm was used in a pilot clinical study conducted in Sweden in 2011–2013, where data collected from 2,485 visits to the emergency department made it possible to predict myocardial infarction in a patient with chest pain with an accuracy of up to 94%[8]. The same method was used to determine whether the type of contrast agent used was an independent predictor of acute kidney injury caused by contrast administration after percutaneous coronary intervention[9].

The application of the hierarchical clustering method, which is designed to capture common features between different groups of the observed population in patients admitted to hospital for acute heart failure, made it possible to distinguish three distinct groups of patients with different severity of diastolic dysfunction and increase in LV filling pressures (both parameters are used to determine the degree of LV diastolic dysfunction). This translated into differences in the clinical course, treatment, and prognosis in each of the identified groups[10].

Applications of ML include supervised learning, unsupervised learning, and reinforcement learning11. These models are used simultaneously and their applications tend to overlap. Deep learning is a sub-discipline of ML and involves using algorithms inspired by the human brain, including a class of algorithms called neural networks[12].

## SUPERVISED LEARNING

This is a type of ML in which the computer is taught by being fed datasets with specific labels or annotations. This results in models that can be used to predict or classify future events – or to search for variables relevant to a particular outcome. It often involves classifying observations into one or more categories or outcomes (e.g.: "Does the ECG represent a myocardial infarction, or is it an ST-segment elevation myocardial infarction?").

Supervised learning requires large amounts of data and is time-consuming because the source data must be labeled by humans (input and description of ECG records, echocardiography, angiograms, cardiac MRI results, scintigraphy[13]. Models for automated diagnosis of coronary artery disease, assessment of the presence of coronary artery stenosis, and prediction of major cardiac events based on scintigraphy have already proven to be highly effective[14].

## UNSUPERVISED LEARNING

Unsupervised machine learning aims to discover the underlying structure or relationships between variables in a data set. Model learning using a dataset takes place without specific labels, and the algorithm groups the data to reveal the underlying patterns. It aims to identify new disease mechanisms, genotypes, or phenotypes[15].

→ **Unsupervised learning algorithms, including artificial analysis neural networks, have proven useful in automatic differentiation of hypertrophic cardiomyopathy (hereditary left ventricular hypertrophy) from physiological left ventricular hypertrophy, as observed in athletes[16].**

Thanks to the use of agglomerative hierarchical clustering based on collected phenotypic data, it was possible to create a novel classification of heart failure with preserved ejection fraction – a parameter assessing left ventricular systolic function[17]. Unsupervised machine learning focuses on discovering the underlying structure or relationships between variables in a data set.

## REINFORCEMENT LEARNING

This type of learning, based on behavioral psychology, makes use of an alternative approach in which the program operates in a predetermined environment to maximize reward. This way, the program identifies the correct behavior using "reward criteria" to impact the decision-making process. It tries to carry out a task (e.g. drawing medical conclusions) by learning from its own achievements and failures. The main goal of reinforcement learning is to maximize the accuracy of algorithms through trial and error. Many clinical problems can be formulated to fit the format of a reinforcement learning problem. Therefore, reinforcement learning algorithms can be used to support clinical decision making, intelligently segment medical imaging data, and select personalized drugs. The application of reinforcement learning in medicine and cardiology has so far been limited. Yet, recent studies have offered promising results: applying reinforcement learning in optimizing therapeutic decisions for chronic diseases and recommending protocols for mechanical ventilator disconnection has produced better clinical outcomes.

## DEEP LEARNING

The application of the convolutional neural network model involves training a set of filters in such a way that the necessary information can be extracted from the provided image. The neural network performs a layer-by-layer analysis of the input data, decomposes the data into features and qualities which are then searched for among records in close proximity. This makes it possible to extract further, more general properties of the data, which are organized as points on a plane with a specific topology. This type of learning is a platform for image recognition applications that can be used in cardiovascular imaging modalities (e.g. angiography, echocardiography, computed tomography, cardiac magnetic resonance, intravascular ultrasound, and optical coherence tomography)[18].

## CONCLUSION

Artificial intelligence has sparked a paradigm shift in healthcare thanks to the advanced analytics it has brought about. The potential applications of AI in dealing with cardiovascular diseases include automated analysis of images and video recordings for rapid and reliable diagnosis, prognosis assessment, clinical decision support (e.g. hospitalization for suspected heart attack, decision to perform coronary angiography), innovative approaches to clinical database organization and analysis, and robotic assistance in percutaneous coronary procedures or cardiac surgery. Artificial intelligence will not only reach a point where it will use real--time scans to detect diseases, but also interpret ambiguous clinical situations, accurately diagnose phenotypically complex diseases, and make medical decisions – including suggesting personalized treatment plans.

**MAREK TOMALA**

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**Angiography** is a diagnostic imaging procedure using contrast and X-rays to assess the condition of blood vessels – such as coronary arteries.
**Cardiac MRI** is an imaging method that uses the signal emitted by hydrogen nuclei contained in water molecules in the human body vibrating in a magnetic field to create an image. The recorded energy is emitted as a radio wave and transformed into an image of the tissue, making it possible to diagnose pathology at an earlier stage than other methods.
**Scintigraphy** is an imaging technique that uses radioisotopes to assess the blood supply to the left ventricle, usually at rest and on exertion.
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**Optical coherence tomography** is a method of imaging the coronary arteries based on the analysis of a reflected beam of visible light, emitted by an optical fiber placed in the coronary artery.

**Marek Tomala, MD, PhD** – specialist in internal medicine, specialist in cardiology, doctor of medical sciences since 2012 (title of doctoral dissertation: "Assessment of right ventricular damage and function in patients with inferior wall infarction treated with interventional therapy"). Professional interests: acute circulatory failure, cardiogenic shock, interventional treatment of myocardial infarction. Author and co-author of several original scientific publications. On a daily basis – a workflow coordinator at the Intensive Cardiac Care Unit of the Clinical Department of Interventional Cardiology at the John Paul II Hospital in Kraków, Institute of Cardiology of the Jagiellonian University Medical College, where patients are treated immediately after interventional procedures in the acute phase of myocardial infarction.

Example of application

# AI saves patients' hearts

Tomasz Jaworski

## → In 2017, 1.6 million people in Poland suffered from ischemic heart disease. That's 4.2 percent of the population, more than in the European Union

Coronary artery disease (CAD) is the main cause of death worldwide and in Poland. Although modern diagnostic tools save the lives of patients suffering from CAD, there are still significant risks associated with invasive diagnostic procedures. LifeFlow, a Polish MedTech startup, uses Microsoft Azure environment (machine learning and high computing power) to design and create 3D artery models and blood flow simulations. Data are stored on the highly secure Azure cloud platform. As a result, LifeFlow is one of two companies in the world to have developed an imaging solution that enables non-invasive CAD diagnosis and can be widely offered to save lives worldwide.

**→ Committed to improving the quality of life for patients affected by coronary artery disease, LifeFlow supports cardiologists with diagnostic technology that can significantly reduce the need for invasive angiography, which entails risks ranging from kidney damage to heart attacks and strokes. An important thing to mention here is that the price of this technology is very affordable.**

## NON-INVASIVE AND RISK-FREE DIAGNOSTICS

The way this AI-based diagnostic works is simple: cardiologists upload patient data, including heart CT images and blood pressure signals, through a user-friendly platform to the highly secure Microsoft Azure Blob Storage service. These data are then fed into the system and used to create models of arteries and blood flow simulations – 3D modeling and processing of diagnostic data would be impossible without the use of artificial intelligence and Azure's high computing power. "Cardiologists can examine coronary vascular function using 3D reconstruction of the arteries. They can take measurements in a virtual environment without exposing the patient to risk and without time pressure. This is a completely different way of making a diagnosis, one that eliminates unnecessary invasive procedures, which are also often quite expensive for the patient," says Wojciech Tarnawski, PhD, Eng., LifeFlow CEO[1].

"As a company, we strive to make a big impact on the way patients are treated around the world. Hardware solutions would require us to set up our servers in hospitals, and it would take years to reach everyone who might need them. We knew that if we wanted the solution to be widely available and help save lives globally, we had to develop it through the cloud and with an experienced partner who understands how healthcare works. Microsoft is a partner that provides us with everything we need," explains Piotr Koryl, COO at LifeFlow[2].

To be able to act on a large scale, a cloud computing diagnostic service is the best solution.

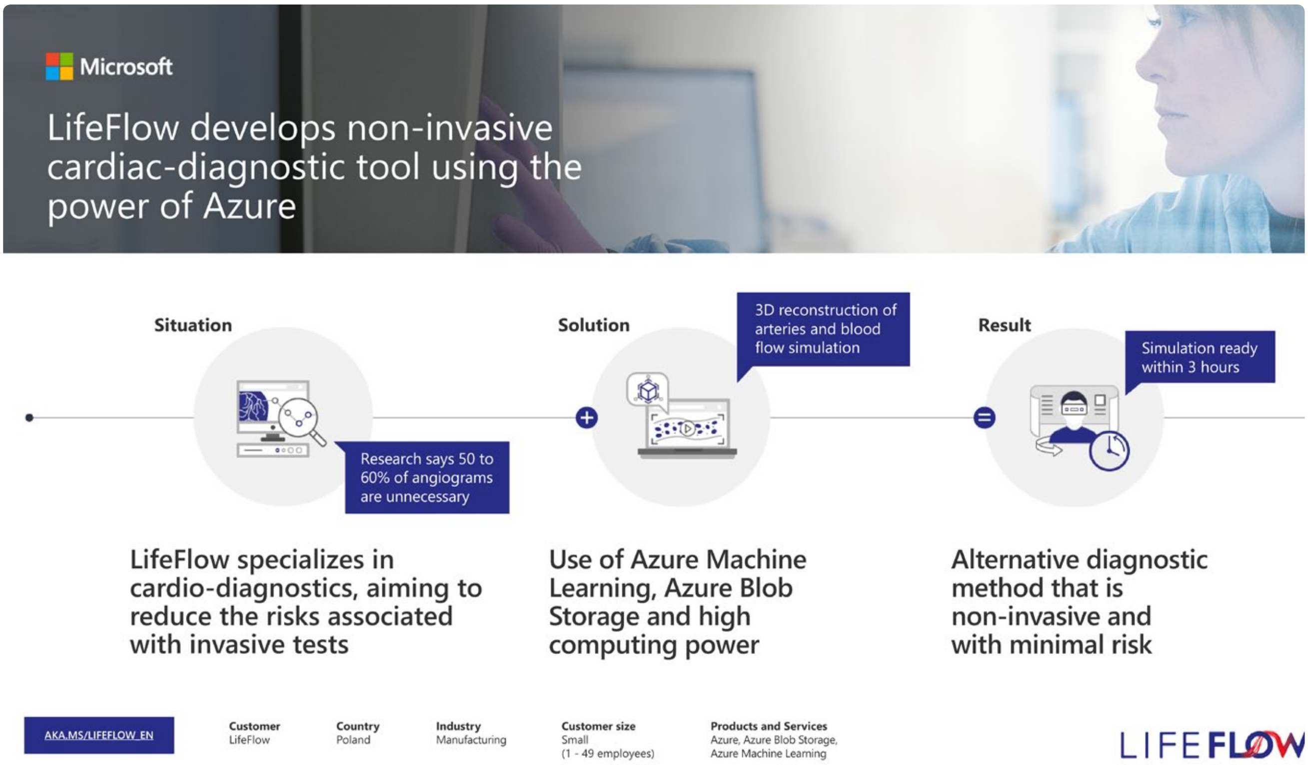
"The most computationally intensive part of our product is the computer simulation of blood flow, so we needed it as soon as possible. Microsoft Azure lets us deliver results faster by making scalable virtual machines available on demand around the world. With the Azure platform, there are no limits to computing power and memory," adds Koryl. Wojciech Tarnawski, in turn, recalls that before the cloud could be used, simulating a patient's blood flow took several days. "By switching to Azure, we reduced that time to about three hours. – he adds. – What's more, because everything runs in the cloud, the company doesn't have to worry about local hardware, wherever it is located. The scalability of cloud computing is a natural choice for complex computational fluid dynamics."

With Microsoft's support, the company got ahead of its competition.

"Since the very beginning, we have been making use of Microsoft for Startups, a three-year Microsoft program that offers expertise and support in the form of licenses to use Microsoft products. This 'marked out' a pathway that allowed us to develop our solution for diagnosing atherosclerosis by virtually simulating a patient's blood flow. (...) Cardiologists can study the coronary arteries through virtual three-dimensional reconstruction of the arteries. (...) This is a completely different way of making a diagnosis, one that eliminates unnecessary invasive procedures, which are also often quite expensive for the patient," concludes Tarnawski.

## ISCHEMIC HEART DISEASE IN POLAND

Over 100,000 Poles die from ischemic heart disease (IHD) every year[3]. In 90% of cases, the disease appears in people with hypertension, diabetes, who are overweight, or those who abuse alcohol and eat unhealthily. So it often occurs as a consequence of what is within patients' 'circle of control'.



Based on the NHF report presented on 24 April 2020, it appears that the payer has made the prevention of ischemic heart disease a priority in its 2019-2023 strategy. It includes:

- increasing patients' access to early cardiac rehabilitation;
- prevention of modifiable risk factors for IHD.

In order to achieve the above goals by 2020, the National Health Fund has launched the KOS-zawał ('KOS-heart attack') program, as well as the CHUK cardiovascular disease prevention program4. In the case of the CHUK program, a pay-for-performance mechanism has been in place since January 2020 to provide additional primary care bonuses when a sufficient proportion of the population is covered by the program[5].

LifeFlow's AI-based solution makes early diagnosis and prevention of ischemic heart disease more accessible to a wider range of patient groups by providing complete anatomical and functional diagnostic information. Currently, it can be obtained only through highly invasive procedures, i.e. coronary angiography. Since LifeFlow's diagnostics is non-invasive, patients are more willing to participate in prevention programs. Automation makes it possible to pre-process images and data acquired from diagnostic tests. This allows the physician to be more comfortable evaluating test results – and help more patients. Both of these phenomena translate into a higher quality of public healthcare and lower costs thanks to the possibility to diagnose a disease before it fully develops, as well as into a variety of other advantages, in line with the Value Based Healthcare (VBHC) practice.

→ **According to the Institute for Health Metrics and Evaluation (IHME), 1.6 million people in Poland (4.2% of the population, which is a higher percentage than in the European Union) suffered from IHD in 20176. The potential to improve the overall level of health and the outcomes relevant to doctors, citizens, and politicians is therefore enormous.**

**TOMASZ JAWORSKI**

*(The author's profile is included in Chapter I.)*

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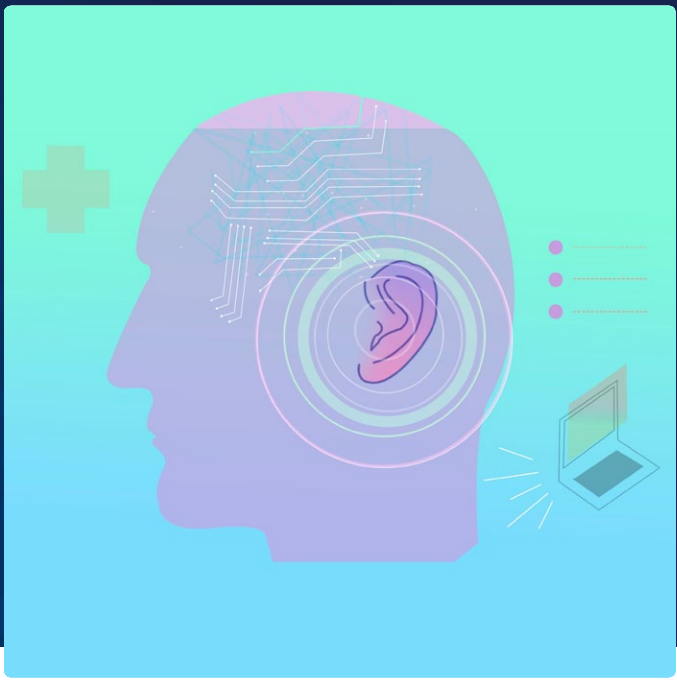
# Otorhino-laryngology /sensory organs

PIOTR H. SKARŻYŃSKI



- **Artificial intelligence is a promising solution in otorhinolaryngology, not only in diagnostics and treatment but also in rehabilitation of sensory organs**
- **AI may find extensive application particularly in hearing, voice, and speech screening, e-health, and otoneurological diseases**

Solutions making use of artificial intelligence (AI) in the field of otorhinolaryngology[1], including in examination of sensory organs, are increasingly popular and provide a valuable basis for the preparation of new studies and implementations. Three main areas can be distinguished here:

1. hearing screening on four continents (Europe, Africa, Asia, and South America);
2. telemedicine solutions including remote ABR[2] testing and remote audio processor fitting – telefitting;
3. otoneurological disorders.

According to the World Health Organization (WHO), approximately 466 million people worldwide have a hearing impairment, and as many as 34 million of this population are children[3]. The same statistics make it possible to estimate that the number of people with hearing loss is steadily increasing, and over 900 million people may be experiencing such problems by 2025. The latest epidemiological data also prove that otoneurological disorders4, such as dizziness and balance disorders, affect 15-20% of the adult population. A number of studies show the importance of early diagnosis of hearing disorders in children and of otoneurological diagnostics, as well as of the implementation of appropriate treatment and rehabilitation.

The audiological care in its present form[5] is unable to meet the global burden of hearing loss due to existing barriers, i.e. lack of trained professionals, cost of equipment, the necessary expertise and know-how, etc. Children – and even adults – are often not diagnosed at all. The reasons for this may be the fact that parents do not make the effort or fail to see that their children may have hearing problems, or that they have to travel long distances or pay a lot to take advantage of diagnostic services. These barriers can be overcome through the use of telemedicine solutions and artificial intelligence, which will translate into the provision of high-quality medical care to patients regardless of where they live or their financial situation.

## HEARING SCREENING

Ear infections are one of the most common causes of pediatric visits[6], so machine learning can be applied to e.g. the analysis of eardrum otoscopy images (assessment of the patency of the ear canal and the structure of the outer ear) or tympanometry (assessment of eardrum mobility). Justin Chan and colleagues[7] have developed a system for detecting fluid in the middle ear, which uses a smartphone microphone and speaker to emit sound and analyze its reflection (echo) from the eardrum. Like in the case of many screening tools, interpretation of results requires an appropriate clinical context, and positive results should prompt further clinical evaluation for potential misclassification.

Currently, artificial intelligence is also used for hearing screening in developing countries[8], where children usually do not have access to such tests. A project using AI assistance (data-driven algorithms and modeling techniques – including machine learning – to generate diagnostic conclusions) offers screening, diagnostics, and referral services in medically underserved communities.

→ **Screening is carried out using an automated test – screening tonal audiometry[9], which can be performed with a smartphone in children aged 3-4.**

If a child fails a screening test, an automated report is generated in the data management portal and sent to supervisors via SMS or email. This clinical decision support system helps local supervisors diagnose hearing loss and refer for specialized care.

Developing AI-based remote screening procedures and making non-medical personnel (e.g. nurses, parents) who may be more accessible involved in these procedures in a sensible manner is the right step forward.

## TELEMEDICINE SOLUTIONS – ABR AND TELEFITTING

In the era of the pandemic, many services are performed remotely due to safety concerns. It is not a novel solution, though. The Polish National Network of Teleaudiology has been operating in since 2007 already, allowing for the use of remote solutions in otorhinolaryngology diagnosis, treatment, and rehabilitation, carrying out remote objective hearing tests (ABR) in places where access to such services is limited or completely non-existent. ABR tests check the response of the auditory system to sound, and the type and severity of hearing impairment can be identified from the response recordings obtained. Such a test can be successfully performed remotely: technicians based at a remote location prepare the patient for the test, and a second (more experienced) technician – present at the medical facility – remotely captures the images displayed on the measurement computer's desktop using online collaboration software.

There is also an option to support trained "remote staff" when diagnosing patients and observing staff practice, thereby controlling the quality of service provided and the standards of patient care at remote facilities. Currently, diagnostic ABR tests are performed by audiology technicians, and the results obtained are evaluated by audiologists or neurologists. Description is based on visual interpretation of ABR waveforms. In order to eliminate subjectivity in ABR test evaluation, there are efforts made to make it possible to use the available AI methods and the associated machine learning solutions to develop an automated ABR waveform analyzer capable of using raw data. Analyzing the provided data, the algorithm would be able to use the available recordings, the indicated latency and amplitude values to determine whether the results show some predictors for normal or rather for pathology. However, the sensitivity and specificity of such a procedure must be very high and based on an optimized set of potential distinctive features of individual otolaryngological conditions[10].

Telefitting (remote fitting of the sound processor) is also a valuable and helpful solution. Each implant patient should be followed up for several years after their procedure to make sure that their hearing rehabilitation is optimal. This, in turn, involves visiting clinics on a regular basis, which can be difficult for many people due to the distance from the clinic, financial issues, etc.

However, this problem can be eliminated thanks to the latest information technology – by incorporating telefitting into daily practice. The course of a telefitting consultation is similar to that of a standard appointment in a medical facility. A specialist from the telemedicine center holds a video conference with the facility which provides the relevant medical services. Since visual and auditory communication is established, it is possible to communicate with support staff, coordinate and verify the correctness of their actions, and – above all – observe the patient. The measurement and programming of the sound processor is performed, in turn, by the clinical engineer taking control of a remote computer using dedicated software.

Experienced clinics that provide telefitting (remote) services on a daily basis could engage more facilities to increase the availability of this solution for patients and therefore, by making use of the latest technology, improve the healthcare system's level and quality of post-operative care offered to patients with hearing implants.

## OTONEUROLOGICAL DISORDERS

In the process of diagnosing otoneurological disorders, including vertigo, the clinician makes use of a unique linguistic pattern that corresponds to an accurate description of complaints in order to assign them to a disease entity. AI is not indifferent here and makes it possible to group symptoms and assign them to common disease entities, such as benign paroxysmal positional vertigo (BPPV), central vestibular disorders, or vestibular migraine, to name a few. A combination of strong consistency of vestibular symptoms and proper targeting to determine the disorder greatly supports clinical decisions and facilitates diagnostics in the outpatient setting. In addition, the use of a binary model improves the predictive power and cross-validation to make a diagnosis associated with more than one disease entity.

→ **For a more accurate clinical practice, a more extensive model can be developed – one that would include three or more symptoms as an indicator of a specific imbalance.**

*Machine learning* can be used as a tool to summarize the most important parameters and to facilitate the interpretation of the overall results – given the long waiting time for the doctor to interpret the results, this certainly saves time during the consultation and accurately represents the actual situation. Artificial intelligence is applied in electrophysiological research, biomedical imaging (e.g. in diagnosing Meniere's disease and balance disorders resulting from structural changes in the central nervous system) or radiology (in determining the size of vestibulocochlear nerve tumors).

It seems reasonable to mention here also the technology of microRNA (miRNA) profiling of the endothelium, collected during surgery and ready to serve as an equivalent of a "liquid biopsy". RNA was isolated from the fluid and microRNAs were extracted to perform sequencing and examine the expression profile. The profiles were then compared in subjects with Meniere's disease, otosclerosis, and sensorineural hearing loss. *Machine learning* (4 types of classification models) was used in the examination. As a result, all models identified two classes of diseases with 100% accuracy. The models for cochlear hydrops showed unique features compared with otosclerosis[11,12], which implies that predictive models for Meniere's disease can be developed. Further work on microRNAs in 'partnership' with *machine learning* should continue because of the potential to discover disease etiology, offer early diagnosis, and take early intervention.

One of the solutions used in the field of otoneurology is diagnostics based on virtual reality, i.e. Subjective Visual Vertical (SVV). The patient uses goggles representing a three-dimensional image and adjusts it vertically using a joystick – the patient is tilted 30° and 45° throughout the examination. Recent studies have shown that there is a very high correlation between the side of the tilt in SVV and the diseased ear in patients with Meniere's disease. The described examination utilizing virtual reality has the potential to be implemented into daily practice outside of otoneurology departments – wherever there are patients who need rapid verification of peripheral and central disturbances associated with postural disorders and vertigo[13].

Telehealth available via smartphone, using AI and an AI-enabled otoneurological disorder diagnosis solution, has a good chance of overcoming many barriers – including territorial, economic, and social barriers – to accessing healthcare services. In developing countries, the proportion of people using smartphones now exceeds 80%, and inexpensive devices and reliable test procedures are becoming available and suitable to performing audiometric[14] and otological diagnostic measurements with acceptable levels of quality and reproducibility. By modifying and upgrading low-cost hardware and equipping it with the necessary software (based on AI), low-income countries can benefit from advanced automated hearing loss diagnostic tools and interventions.

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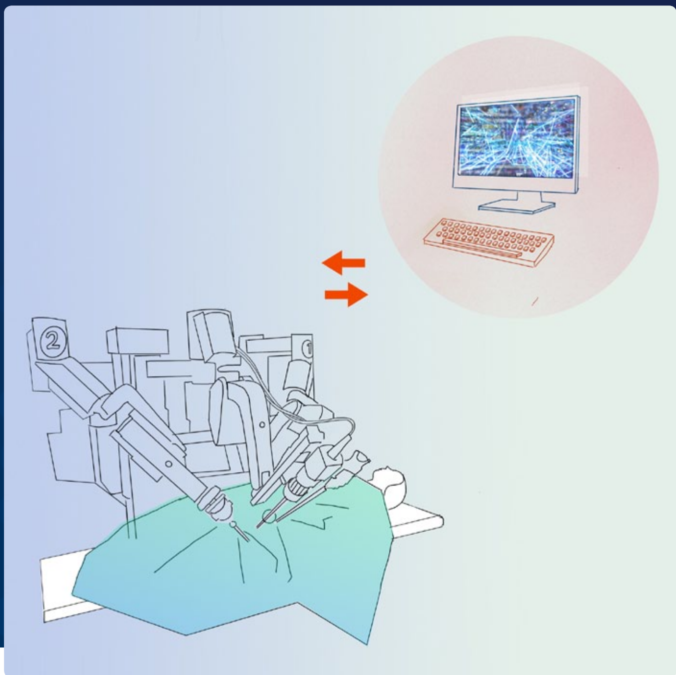
# O medical robots

ZBIGNIEW NAWRAT



→ **After the advances in telecommunications, meaning long-distance transmission of information, it is time for the development of teleaction – long-distance transmission of action. And this is where robots come into play**

→ **Unsupervised medical robots with open access to data and their own sensory system should soon prove very useful as a result of the advances in AI and IoT**

Medical innovations must serve to improve standards, promote access to healthcare services, and make personal optimisation in the care, treatment, and rehabilitation of patients more common. They respond to demographic challenges and the increasing social demands and expectations. Each day brings new challenges – new diseases that reduce the comfort and duration of life and sometimes – as in the case of the recent pandemic – threaten the very existence of our population. Medical services should be performed flawlessly, at the right time and place. This calls for both organizational and technical innovations. The development of medical robotics is an opportunity to solve a significant part of these problems.

## MEDICAL ROBOTS

A robot, as opposed to an automaton, is an intelligent combination of perception (sensors) and action (mechanical work). For robots to make decisions, they must have access to information and the ability to analyze it. Medical robots are used in diagnostics, rehabilitation, and treatment. Automated diagnostic (e.g. CT, NMR – nuclear magnetic resonance spectroscopy) or radiotherapeutic devices are already a common standard. Other robot applications, such as rehabilitation robots or – like in the case of surgical robots – remote control robots, require control and direct supervision. Robots are successfully utilized in the preparation of personalized medicines, in medical and nursing logistics, where they assist staff by performing simple tasks such as transporting items or disinfecting rooms.

**In the world**, the main manufacturers of such devices are: Intuitive Surgical, Inc. (USA), Stryker Corporation (USA), Mazor Robotics Ltd. (Israel), Hocoma AG (Switzerland), Hansen MediCal Inc. (USA), Accuray Incorporated (USA), Omnicell, Inc. (USA), Ekso Bionics Holdings, Inc. (USA), ARxIUM (USA) and Kirby Lester LLC (US), Houston Medical Robotics (USA), Otto Bock Healthcare, Kinova robotics, Varian Medical Systems, Hocoma AG, Vecna Robotics, Globus Medical, IRobot Corporation, Titan Medical, Inc, KB Medical S.A.

**In Poland**, surgical robots are developed by: Professor Zbigniew Religa Foundation of Cardiac Surgery Development (surgical Robin Heart), ACCREA Engineering Poland (training robot).

Polish rehabilitation robots, on the other hand, are the domain of: Łukasiewicz Research Network – Institute of Medical Technology and Equipment ITAM, Industrial Research Institute for Automation and Measurements PIAP, PRODromus (ProdRobot – automated gait trainer), MiDmed (creating robots for post-stroke and oncological rehabilitation). This includes companies offering commercial rehabilitation robots and conducting original research: EGZOTECH, PHU Technomex, Meden-Inmed.

When it comes to diagnostic robots, the entities that specialize in this domain include: Łukasiewicz Research Network – Institute of Medical Technology and Equipment ITAM with Silesian University of Technology; ACCREA Engineering Poland (tele-ultrasound).

A separate domain is robotic pharmacy, which prepares drug doses in individual sets for hospital patients. This is the role of the UniDoseOne Quizit (these are automated dispensing systems for hospital patients).

Care/social robots are the domain of: ACCREA Engineering Poland, AssisTech, HealthUp and Silesian University of Technology with APA sp. z o.o.

There are also disinfection robots, a specialization of ACCREA Engineering Poland, and artificial organs, covered by: vBionic (printed artificial arm/hand) and Professor Zbigniew Religa Foundation of Cardiac Surgery Development (artificial heart and circulatory support systems Religa Heart)[1,2].

→ **In Europe, more and more opportunities are being created in this area for small and larger entrepreneurs. This is thanks to e.g. the support offered by hubs such as the Digital Innovation Hub Healthcare Robotics HERO.**

**Artificial intelligence** is a branch of robotics. The origin of the word "robot" is a play by the Czech writer Karel Čapek, titled "R.U.R." (*Rossumovi Univerzální Roboti, Rossum's Universal Robots*) from 1920, where it meant 'artificial man'. As we know, humans not only perform actions but also think. The role of a doctor is first to make certain decisions on how to act further. Intelligence is about responding appropriately to the stimuli received. The key to bringing intelligence to robotic devices is therefore the acquisition of information (sensors, speech and image recognition) and making good use of it in practice.

**Social robots**, service robots, need to work with humans, and artificial intelligence was created precisely to enable them to communicate with human intelligence. In order for medical robots to use their potential in coping with the challenges of the increasing demand for better and better services to the fullest, they need to become autonomous soon. Autonomous robots should operate in an information network, with access to all the information they need to optimize performance at any time and in any situation.

**Autonomy of medical robots** can be measured on a five-point scale modeled after the SAE J3016 standard (included in publication[1]). Level 1 has been reached already by such robots as da Vinci offered by the American Intuitive Surgical, or by our domestic prototype Robin Heart. Levels 3 or 4 are achieved by e.g. CT scanners or CyberKnife. However, none of the existing medical robots has yet reached level 5 (fully automated operation). In May 2018, Corindus (a robot for invasive cardiological procedures) received U.S. Food and Drug Administration (FDA) clearance for its first robotic robotic motion (CorPath GRX platform) – *Rotate on Retract* (RoR). It was **the first semi-automated robotic procedure approved for clinical use**. The door was swung open.

## PROSPECTS

Statzon's latest report "Global Surgical Industry Report 2021" shows that the global surgical robotics market will grow at a CAGR of around 14% during 2020-2028 (the fastest in India). At present, the U.S. accounts for about 57% of this market, and the EU – for 20%.

The system developed by Intuitive Surgical rewards profitability in instrument sales: 49% of the market. It is probably the cost of the instruments that has led to an increase in the range of applications of AI in specialties that do not require a large number of different instruments to perform a procedure (such as cardiac surgery): general surgery – 35%, gynecology – 25%, urology – 19%. In the US, most urological surgeries have long been performed with the help of da Vinci robots.

**The search for** more areas of application of AI in medicine produces sometimes groundbreaking results. There is a growing interest in the use of a cyber knife for heart surgery. In 2020, at the Oncology Centre in Gliwice, Jacek Bednarek, MD, PhD and his team used the CyberKnife robot to perform radiofrequency ablation of the heart (ablation is a method of treating arrhythmias), i.e. precise creation of a scar (micronecrosis) in the place where the so-called arrhythmogenic substrate is located, by irradiation with a photon accelerator. The technique allows for what is called transmural ablation, which is ablation that targets the entire wall of the heart muscle.

Surgical robots **can learn**. Artificial intelligence has been successful since the emergence of deep machine learning. In the Motion2Vec project, American scientists have shown that it is possible to teach a da Vinci robot surgical suturing by analyzing YouTube videos (based on configurations of deep neural networks – called Siamese networks). **AI** – the Canadian platform BlueDot, to be precise – was the first to **warn** of the COVID-19 pandemic as early as on 31 December 2019.

Social robots are getting better and better at **recognizing and responding to our emotions**. And some, like the PARO seal, a favorite among Alzheimer's and dementia patients, **earn our trust**. The Japanese avatar Gatebox, on the other hand, will make sure to ask us about our day.

It is the development of artificial intelligence that allows companion robots to evolve – they can learn our habits and adapt their 'behavior' and actions to our needs. In the smart/deep care model, robots **relieve** staff of physical tasks to enable them to communicate with patients in a deeper, more personal, empathetic way. Practicing medicine will again become a fantastically challenging art, but with its burdens delegated – much of the workload will be shifted to robots in both the mechanical and mental domains.

**Deeper**: we can go deeper and deeper into the brain (e.g. Neuralink). **Faster**: 5G networks enable download and upload speeds of up to 20 Gbps, supporting up to even one million devices per square kilometer. This can reduce delays in teleoperation by up to 20 times. One of the first pieces of evidence to support the above claim was provided by a Chinese experiment carried out in 2019. Using the KangDuo robot, animal liver surgery was performed from a distance of 50 km.

## CONCLUSIONS

Today, a medical robot is more of an IT tool than a mechanical tool. A physician usually makes decisions with a limited amount of knowledge about a particular patient. With AI supporting the diagnostic process and updating the data analyzed during procedures, we will be able to reduce the risk of making a mistake. AI-based medicine will be personalized by design. The less access to information and the less invasive the procedure, the more important the role of artificial intelligence will be[3]. Medical robots are the only chance to meet the demand for a broad, democratic access to quality healthcare services in the near future. The ongoing demographic changes, the shortages of medical staff, and the need to improve the standards of services provided in hospitals, clinics, and nursing homes are global trends that call for a greater involvement in the field of medical robotics (including the development of artificial intelligence). In view of these challenges, Poland has a good chance of becoming a significant provider of medical robots.

**ZBIGNIEW NAWRAT**

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**Zbigniew Nawrat, MD, PhD, DSc** – scientist, inventor, teacher, visionary, award-winning pioneer of medical robotics. He has incorporated medical applications of virtual space technology and surgical simulation methods which he has been developing with his team into the domain of research. An expert in the field artificial organs. The POLVAD ventricular assist devices he has designed have been saving patients' lives since 1993. He is called the father of the Robin Heart robot – the first European surgical robot, which has a chance of being adopted for clinical use soon. He co-created the early design of the Polish artificial heart and co-founded Heart Prostheses Institute (HPI) in Professor Zbigniew Religa Foundation of Cardiac Surgery Development (FCSD), which he ran from 2007 to 2019 (from 1998 to 2007 vicedirector HPI , he's currently its Creative Director FCSD). He is a teacher of students from 1984, working 30 years in Cardiac Surgery Department, now as Assistant Professor at the Department of Biophysics of the Medical University of Silesia. He is founder and President of the International Society for Medical Robotics (www.medicalrobots.eu) and editor in chief of the journal "Medical Robotics Reports". Influential promoter of innovative medicine as organizer of popular conferences and scientific meetings and surgical workshops. Co-author and author of books and patents, several hundred scientific articles.

# Artificial intelligence and medical facility management

ŁUKASZ BRUSKI

→ **Artificial intelligence applied in medical facility management is an opportunity for improvements and changes in the spheres of management, organization, and finance**

→ **Application of AI will translate into improved quality of staff performance and services offered to patients of medical facilities**

Computers and calculating devices have long been used both in hospitals and throughout the healthcare sector understood in broad sense. Starting from performing simple mathematical calculations, smart technologies have evolved to the level of multi-module hospital information systems available today, whose most important management tasks can be summarized in the following points:

- improving the quality of patient care;
- improving the quality of management and thus streamlining and reducing the costs of hospital operation;
- reduction of administrative work;
- provision of information for economic and financial analysis and quality control and research.

Such extensive systems require medical facility managers to make significant investments in the necessary equipment, such as servers, supporting devices, and cable and wireless network infrastructure. An additional element that we should bear in mind is the security measures required for this type of network, not only "physical" but also "digital", i.e. covering software in use and the data collected and processed. Nevertheless, these are investments which, if made in a planned, well-thought-out manner, pay off by significantly improving the quality and speed of work.

Collecting such large amounts of medical and management data in digital format has enabled the implementation and rapid development of artificial intelligence in medicine. Below follow examples of its practical implementation in healthcare, describing the improvements achieved in the processes carried out in medical facilities:

## IMPROVING THE QUALITY OF MANAGEMENT OF MEDICAL RECORDS

Artificial intelligence and machine learning can directly impact medical data management. Both of these solutions enable physicians and administrative staff to make more efficient use of the records and data they collect. Data such as, for example, disease descriptions and entities, test results, number of procedures performed, prescriptions, invoices, receipts, and sick notes, had been most often kept in a disorganized manner, which made it difficult to analyze them easily and efficiently.

This has changed thanks to the use of artificial intelligence and machine learning, allowing users to quickly access the data they need, organize it appropriately, and assign it to specific analyses and reports. In addition, it has offered a possibility of making independent conclusions regarding the processes taking place in medical facilities and the links between them, providing huge room for improvement as well as a stimulus to undertake initiatives to improve management efficiency. A separate issue to be raised is granting doctors faster access to medical records which, in a processed form, can be the basis for faster decisions on the appropriate treatment, increasing the effectiveness of the therapies given, which translates into a high level of patients' satisfaction and quality of life.

## AUTOMATION OF PROCESSES GOVERNING PATIENT RELATIONSHIP MANAGEMENT

Each one of us must have had to deal with medical customer service at least once when, for instance, trying to make a doctor's appointment. Difficulties with getting through on the phone, receiving answers to the questions asked, or lack of any response to the messages sent is surely something everyone is familiar with. This is very often due to the multitude of tasks to be performed by those employed in such organizational units and because of staff shortages.

Therefore, there is a huge potential for the application of artificial intelligence in this field. In patient care, there are a lot of simple, repetitive processes that can be easily automated – without the use of AI. However, the adoption of artificial intelligence makes it possible to e.g. understand patient inquiries and prepare correct answers to be sent to them in response. It is possible to program the exchange of information, making appointments, following up on appointments or hospital stays, as well as providing information about the medical facility itself and its staff.

→ **The currently used chatbots, utilizing artificial intelligence, work with systems such as CRM[1], based on data in advance from questions asked and answers given.**

Building such knowledge libraries is one of the many challenges to be faced by healthcare facilities for this solution to be applicable on a mass scale.

## AUTOMATION OF FINANCIAL CONTROLLING

Large healthcare facilities, as well as networks of clinics and doctor's practices carry out thousands of non-medical processes in their daily operation – such as accounting or administrative services. Every day they receive and process many invoices, bills, contracts, and official letters. The digitalization of incoming financial documents, automatic entering of these documents into dedicated systems (e.g. accounting systems), and the use of artificial intelligence are bound to make ongoing financial controlling even more effective. This translates into the optimization of the cost structure, full control over cash flows, formation of an optimal organizational structure, having a reasonable investment policy in place, and makes it possible to achieve satisfactory financial results in short settlement periods. Such a digital ecosystem is also able to signal in advance undesirable events that may affect the financial situation of a given medical facility.

## IMPROVING THE EFFECTIVENESS OF NON-MEDICAL HOSPITAL PROCEDURES

Artificial intelligence enables healthcare facilities to make use of predictive analytics to improve the efficiency of hospital procedures. This involves the use of IoT (Internet of Things) solutions – such as RIFD (*Radio Frequency Identification*) tags – to locate hospital staff, equipment, or medical devices. Installing the necessary technological infrastructure on the premises of a medical facility makes it possible to collect the necessary data, which, analyzed by AI, produce a result in the form of solutions with the potential to improve many procedures – including those governing internal logistics, efficient deployment of hospital resources, or optimal use of human resources together with their allocation.

One of the most important processes occurring in every medical facility is the process of supervision of medical equipment and medical devices. It is governed by various laws and requires the involvement of many employees. When IoT and AI solutions are used, the hospital is able to automatically identify its needs related to the operation and maintenance of its equipment, the need to perform required inspections and servicing, and better use of its diagnostic capabilities. Ultimately, this translates into a growth in the number of patients admitted, an improved overall access to medical services, and thus also to an increase in revenues.

## IMPROVING THE QUALITY OF MEDICAL RECORDS COLLECTED

A trend that has been on the rise in healthcare is to increase the administrative burden on doctors and medical facilities. This is due to a number of reasons, e.g. the need to account for and receive payments for medical procedures performed on behalf of the payer when organizations appointed to distribute funds intended for public/private healthcare are obliged to verify cash flows. To this end, these organizations require physicians to carefully document the medical procedures performed. Thus, physicians are obliged to make descriptions and fill out all sorts of different forms.

Similarly, the regulator – meaning the Polish the Ministry of Health, imposes through its regulations further obligations concerning the keeping of detailed medical records in order to secure and protect patients' rights. This requires physicians to spend much more time typing text into the computer and very often duplicating the same data multiple times in different forms and across different computer systems – instead of spending that time addressing the patient's needs. The use of artificial intelligence solutions makes it possible for physicians and administrative staff to save a lot of time, automatically linking data entered in one place with other forms and medical documents required in the process of patient treatment, as well as those imposed under the legislation in force.

## AUTOMATION OF WAREHOUSE MANAGEMENT

Medical facilities, just like all businesses, must have a stock of resources necessary for everyday operation: medicines, medical devices and instruments used e.g. in surgery, dressing materials, or consumable accessories for medical equipment. In light of the legislation in force, these resources are governed by different requirements regarding how and where they should be stored and transported as well as concerning their shelf life. It is a frequent practice to see each of the hospital wards or other organizational units of a medical facility running its own warehouse. Unfortunately, this results in inefficient warehouse management, which generates unnecessary costs and leads to organizational problems.

This is where artificial intelligence excels, being able to combine information on current stock levels, storage methods, and expiry dates with the scheduled medical procedures and patient numbers – and translate these data into the necessary purchase decisions (by placing relevant orders with suppliers or transferring stock between individual organizational units). The outcome of these actions is a reduction in the amount of stocks in the warehouses of medical facilities, as well as an almost complete elimination of resources which should be disposed of due to the fact that they are no longer fit for use. These actions translate very quickly into tangible gains shown in financial reports.

## TRANSCRIPTION SYSTEMS

Natural language processing (NLP) is often considered one of the branches of artificial intelligence. Due to legal requirements, which require very precise documentation of the course of visits and medical activities performed to benefit the patient, this technology has great potential to improve the daily work of physicians. Relieving medics from the need to independently type text using the keyboard significantly increases the quality of patient service – as well as the efficiency of their work. Therefore, the use of automated transcription systems utilizing NLP seems to be a natural and anticipated outcome of the implementation of artificial intelligence in medical facilities.

## A SMART HOSPITAL OR CLINIC BUILDING

Managing properties which accommodate or act as medical facilities is another area where artificial intelligence can work wonders. Managing heating, air conditioning, medical gases, lighting, water supply, medical and municipal waste, supervising the devices and systems required for proper and safe functioning of the facility – these are only some of the most important examples. By installing sensors and connecting devices to a single system, we gain the possibility to manage a property in a comprehensive manner, supervise its operation on an ongoing basis, and meet the relevant requirements. An obvious outcome is the reduced amount of costs involved in the operation of the property.

The examples provided show clearly how AI can be or is being used in the daily operations of clinics and hospitals. The potential for applying this technology in the domain of management of healthcare facilities is enormous and growing. The increasing number of new diagnostic methods and expensive devices, the rising costs of operating medical facilities, the increasing administrative burden combined with a simultaneous shortage of specialists – all this makes for a perfect environment for the practical adoption of AI-based solutions. The most promising of them include systems enabling autonomous optimization of processes governing the functioning of medical facilities. These processes have to do with both the infrastructure in place and its use, warehouse management, human resources, and medical devices. 'Hiring' a digital office assistant relieves the doctor from having to prepare medical records on their own, allowing them to fully devote their time and attention to the patient and the relevant medical procedures. This also translates into better medical record keeping and, consequently, further improvements in diagnostic, treatment, and rehabilitation processes.

The use of IoT and AI opens up entirely new opportunities for improvement, transforming the way medical facilities operate in terms of management, finance, and organization. Successive increase in the amount of collected data and monitored parameters, followed by their subsequent multifaceted analysis carried out with the use of AI will result only in benefits for the operation of healthcare facilities and for the quality and efficiency of the medical services they provide. It will directly affect treatment outcomes, improve the level of patient satisfaction, and enhance the quality of patients' lives. Obviously, it will also have a positive impact on the financial performance of medical facilities.

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**Łukasz Bruski, MD, PhD, MSc** – involved in medicine for over 20 years, currently President of the Management Board of Centrum Słuchu i Mowy sp. z o.o., employed also at Instytut Narządów Zmysłów sp. z o.o. Graduate of the Warsaw University of Technology, SGH Warsaw School of Economics, and postgraduate studies "Managing Healthcare Facilities" at the SGH Warsaw School of Economics. He defended his doctoral dissertation titled "Evaluation of clinical and economic effectiveness of telefitting for patients with hearing implants" at the Second Faculty of Medicine at the Medical University of Warsaw. Participant of the Canadian Executive MBA program at the University of Quebec. Author and co-author of many publications and presentations on the application of modern technologies in medicine. His achievements include publications in domestic and international peer-reviewed journals. He has participated in many congresses, training programs, conferences, and meetings organized both in Poland and abroad. Since 2006, he has delivered lectures he has prepared on his own or as a co-author at more than 60 events taking place domestically and internationally. Manager or coordinator of many projects co-financed from EU funds, including R&D projects whose results have been implemented in medicine and business.

Example of application

# Artificial intelligence in CODP

Tomasz Jaworski

## → Personalized care in COPD results in better treatment outcomes and cost savings. The key is the use of artificial intelligence

By 2030, COPD – chronic obstructive pulmonary disease – will become the third most common cause of death worldwide. WHO estimates that over 250 million people in the world suffer from it, and according to the Polish Ministry of Health, there are nearly 2 million people suffering from COPD in Poland. Quick diagnostics and selection of appropriate treatment is a challenge which the healthcare system in Poland (as well as in other countries) still fails to fully cope with. The symptoms of COPD are non-specific, and many patients underestimate them or confuse them with symptoms of respiratory infections, asthma, heart disease, or aging. According to the Polish Phtysiatry and Pneumonology Association, there are four stages of COPD. The symptom which alarms patients because of its severity appears late, when about half of the respiratory surface of the lungs is irreversibly damaged.

### CASE ONE: IMPROVING TREATMENT OUTCOMES. NHS SAVINGS

NHS Greater Glasgow & Clyde[1] is testing a novel way of using artificial intelligence to detect trends in patients with chronic diseases such as chronic obstructive pulmonary disease. Since each unplanned hospital visit costs around £6k, technology could play a huge role in reducing NHS spending required to manage care plans for the chronically ill.

As Dr. Chris Carlin, consultant respiratory physician at NHS Greater Glasgow & Clyde, points out: "Our hospitals are overfull, and we are struggling with resource to manage increasing numbers of hospital admissions, so we've got to look at strategies that can tackle all of this from both from the patient focus and from the health care organisation focus"[2].

**The main goals of the program, which is to benefit 400 patients, are:**

- Improving treatment outcomes: "COPD affects 1.2 million patients in the UK. If we're able to predict what may happen with a patient, we can change that patient's treatment so they can avoid a hospital admission" (Dr. Chris Carlin,)[3];
- Contributing to savings for the NHS: "If we can upscale this and provide this treatment to 400 patients, would equate to an NHS cost saving of £1.2 million per year" (Dr. David Lowe, Consultant Emergency Medicine, NHS Greater Glasgow & Clyde)[4];
- Engaging patients to work together: "Equally as important is self-management: that ability for the patient to be able to monitor their own symptoms and to proactively manage their condition" (Dr. David Lowe, Consultant Emergency Medicine, NHS Greater Glasgow & Clyde)[5].

NHS Glasgow & Clyde's implementation is being carried out in collaboration with partner company KenSci and makes use of Microsoft's off-the-shelf AI solutions to ensure compliance with current regulations and a high level of cybersecurity.

### THE USE OF AI IN CHRONIC DISEASES

The project run currently in the NHS focuses on COPD. However, the existing literature on the subject suggests that artificial intelligence may prove equally useful in managing patients with other chronic diseases – such as diabetes and cancer. Dr. Carlin, quoted earlier, concludes: "You're able to see individual benefits, you're able to see an ability to deliver treatment to patients in a realistic fashion, you're seeing improvements in quality of life, you're seeing positive changes for the NHS and also you're seeing that you're moving towards the future vision"[6].

## CASE TWO: TELEMEDICINE IN SCREENING IN POLAND

→ **In Poland, over 300 doctors and clinics use a system called AioCare[7]. It is a professional system for diagnosing and monitoring respiratory diseases, consisting of a medical device (portable spirometer), a mobile application, and an online panel for reading measurements.**

A certified medical device makes it possible to perform a complete spirometric examination – including a diastolic test. AI-based diagnostic algorithms help to simply and clearly interpret measurements and automatically detect coughing during the examination.

AioCare makes it easy to monitor patients' health, detect early signs of diseases such as asthma or COPD, and control the taking of medications. Patients can use AioCare at home, and the doctor keeps track of their results in real time and is able to consult them as necessary. Spirometry without leaving home, fast test results, and phone or video consultation with the doctor have been highly rated by both patients and doctors.

AioCare engages the patient, making it possible to monitor health conditions, disease symptoms, and medications in a day-to-day setting. The doctor can display the data in real time in their panel. Care organized with the incorporation of telemedicine and AI lets patients avoid unpleasant disease exacerbations and take advantage of personalized treatment based on actual results. The therapy of patients with respiratory failure (COPD, obesity hypoventilation syndrome OHS, neuromuscular diseases) or with breathing disorders during sleep (obstructive sleep apnea) can be successfully carried out in a telemedicine model thanks to at-home mechanical ventilation (WM) or so-called continuous positive airway pressure (CPAP) therapy. This model of care has been implemented in France by Philips, contributing to better medical outcomes for patients and to savings for the payer.

The research is conducted jointly with the Polish Federation of Asthma, Allergy and COPD Patients' Associations. AioCare, as a Microsoft partner, uses Azure technology and machine learning (ML) to pre-assess spirometry results – and develops advanced prediction methods.

**TOMASZ JAWORSKI**

*(The author's profile is included in Chapter I.)*

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# Application of AI in public health

GRZEGORZ JUSZCZYK,
STEFAN BOGUSŁAWSKI,
PIOTR BURLIŃSKI

- **The increasing detail and scope of available data will allow AI methods to be used to analyze population health at local and global levels**
- **AI-based analytical systems will complement rather than replace traditional analytics as a basis for public health decision-making in the near future**

The computerization of the healthcare system is a phenomenon whose dynamics is constantly accelerating, and the amount of data collected will keep on growing in the foreseeable future. The digitalization of medical records, the collection of data on population lifestyles, environmental, and climate factors, the development of monitoring technologies, supported by the deployment of 5G and IoT network technology, and the general shift towards data-driven decision-making all suggest that the growth of the amount of such data will continue to be exponential. This large amount of data allows public health to be analyzed in a whole new way, using multidimensional and multivariate analyses.

However, taking full advantage of this potential exceeds the analytical capabilities of humans and calls for supporting technologies – such as artificial intelligence (AI) in its broadest sense. Extending the use of AI in the areas described below and overcoming existing challenges will determine the major directions for public health analytics in the next decade.

## APPLICATION OF AI IN PUBLIC HEALTH

### EPIDEMIC NOWCASTING AND FORECASTING

There have been numerous attempts around the world to use AI in morbidity analysis. Two main trends can be distinguished here[1]:

**Epidemic nowcasting** – using AI to analyze live data (provided with as little delay as possible) to detect emerging outbreaks and to assess the current scale of the epidemic, even before any record of it in the healthcare system, as an early warning system. This is made possible thanks to automatic analysis of data such as web and search traffic, automatic analysis of article content and comments, local drug purchases, and people mobility.

**Epidemic forecasting** – using AI's potential to incorporate phenomena invisible to humans to predict the development of epidemics at the global and local levels, allowing for the preparation of responses in a targeted manner (precision medicine). The data that can be used are primarily information on benefits, drug purchases, weather forecasts, distribution information, and population movement. Studies show high effectiveness of AI in predicting the course of epidemics in a short-term perspective (2 weeks)[2].

#### ANALYSIS OF FACTORS AFFECTING PUBLIC HEALTH

A simultaneous automated analysis of multiple datasets can make it possible to discover correlations that would not make it otherwise to the realm of hypotheses resulting from traditional analyses. Health measurements can be analyzed in the context of lifestyles (including diet), climate change, environmental pollution, access to healthcare, education, wealth, population migration, and any other environmental-economic-social phenomena[3].

A Polish example of the above is the implementation of the Profibaza project by the National Institute of Public Health – National Institute of Hygiene, which will make available data on the health situation of the population and on the implementation of health programs for the purpose of disease prevention and health promotion in Poland. AI algorithms are expected to allow the evaluation of the effectiveness of disease prevention and health promotion programs in preventing and reducing the prevalence of chronic diseases analyzing historical data dating back to 2006. Other areas where the use of AI is being considered include modeling the effects of climate change on the local occurrence of certain insect-borne diseases or evaluating the effects of diet using data collected from large populations.

#### ENHANCING DATA SETS THROUGH AUTOMATED ANALYSIS OF MEDICAL RECORDS

Another area is the use of AI to improve and enrich datasets using natural language processing (NLP) analysis. An automatic analysis of the content of medical records with the classification of symptoms and procedures would open the door to the analysis of the real course of diseases and their treatment, far broader than the one subject to manual systematization practiced today. The development of this technology could also potentially reduce some of the administrative burden on healthcare providers while significantly enriching databases for public health analysis. This area covers also the enrichment of additional information about the patient, which may be found in the documentation, and even in the records of paramedics' conversations (e.g. identifying the social background of an intervention[4]).

#### KEY CHALLENGES LIMITING THE USE OF AI IN PUBLIC HEALTH

Using the objective opportunity offered by the development of AI technologies in public health is limited by a number of constraints and challenges. Some of them are related to the very nature of AI technology, and confronting them may require changing some analytical paradigms.

Such a challenge is the **complex process of justifying** the result obtained (AI is largely a so-called *"black box"*, in which the details of the computational process are hardly traceable)[5].

→ **Mindless use of AI may raise legal and ethical challenges in the future, e.g. when deciding where to spend public funds or determining risk groups.**

This challenge becomes also greater when one considers the unpredictable outcome of the **evolution of the scope and quality of the data used**, which can lead to spikes in the results of continuous analysis. **Poor data quality** and **short time frame available** limit the effectiveness of the learning algorithm – both of these factors affect the Polish system of medical statistics. **The relatively short history of the use of AI methods** for forecasting means that their medium and long-term effectiveness has yet to be seen.

The last but not least important factor is **AI's** ability to **discriminate against subpopulations that are unrepresented or misrepresented in the datasets** (which can be due to a variety of reasons)[6]. In such a situation, decisions based on the results obtained may be discriminatory (and the analysis of such cases will be hampered by the *"black box"* mechanism described above).

The challenges discussed above point to the need for great caution when using AI methods in practice. It is reasonable to expect that in the foreseeable future it will be necessary to validate AI methods by means of parallel traditional analyses, which will gradually become control analyses over time.

### PROSPECTS

Looking into the next decade, the key to the development of AI applications in the area of public health will be the integration and systematization of available data sources in the area of both the population health status and the possible external factors that affect it. It is crucial to make sure that the quality of the data collected is continuously improved – and to train analytical teams capable of interpreting such data. It is also important to reduce data access time as much as possible while expanding the scope of the data considered.

At the same time, there should be ongoing research conducted and attempts made to use AI in the identified areas of public health. An advantageous situation would be to develop a habit of performing AI-based analyses in addition to analyses carried out by means of traditional methods. This would make it possible to popularize AI applications among researchers, providing them with a safe environment to develop AI-based methods while maintaining the possibility to compare the results produced by both methods.

## CONCLUSIONS

The development of AI-based analytical methods is the future of public health research; however, it is unclear whether, when, and under what conditions these systems will be able to completely replace alternative methods as a basis for decision making. It is possible that at first, AI methods will be more effective and safer when used to make a great number of decisions of lesser significance. This limits their utility in the support of decision-making in public health, which generally involves making a small number of important decisions. The prerequisites for the development of AI methods are access to integrated data and the development of a skilled, courageous research workforce.

→ **The Covid-19 pandemic has highlighted the global unpreparedness of healthcare IT systems to monitor and predict the spread of infectious diseases.**

Overcoming today's challenges that limit the development of AI technologies in the area of population health monitoring is one part of preparing to effectively combat the possible pandemics of the future.

**GRZEGORZ JUSZCZYK,
STEFAN BOGUSŁAWSKI,
PIOTR BURLIŃSKI**

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**Grzegorz Juszczyk, MD, PhD, DSc** – a public health expert, the director of the National Institute of Public Health since 2017, conducting research in the areas of population health monitoring and analysis, health promotion and prevention of infectious and chronic diseases, food safety, and the environment. In 2019, he managed the process of merging the National Institute of Public Health – National Institute of Hygiene and the National Food and Nutrition Institute, which was completed on 1 February 2020. He also made it possible to expand the scientific team and activity of the National Institute of Public Health – National Institute of Hygiene to include nutrition research and nutrition education. Member of the National Council for Oncology; academic teacher at the Medical University of Warsaw.

**Stefan Bogusławski, MD** – Chief Specialist at the Department of Population Health Monitoring and Analysis of the National Institute of Public Health – National Institute of Hygiene. Involved in healthcare research and consulting for nearly 30 years. His professional experience includes many years of managing Sequence and PEX PharmaSequence – Polish consulting and research companies, as well as the Polish branch and Central European region of IMS Health (currently IQVIA), providing information, services, and technologies for the medical industry. Participant of a number of Polish and foreign courses and training programs in the field of general management, market research, and analytical methods. Author of a number of papers delivered at many conferences in Poland and abroad, publications featured in the general and trade press in the Polish health market – with a particular focus on the pharmaceutical market.

**Piotr Burliński** – an expert in the healthcare market, specializing in designing and performing advanced business analyses, developing strategies, and structuring information. He has over ten years of business experience in the pharmaceutical market, distribution of medicinal products, and mergers and acquisitions. He develops his knowledge and competence in the areas of health economic theory, study of inequalities in access to healthcare, and the principles of organization and maintenance of knowledge bases.

Example of application

# Value of medical care

Tomasz Jaworski

## → Value in health care can be defined as the quality of care as perceived by the patient

"Health care is a commodity — something we pay for. There is increasing recognition that, as with any other product, we should aim to get the best "bang for the buck" from health care, with the goal ultimately being improved health" – we can read in the article titled "Defining Value-Driven Care in Head and Neck Oncology", published in "Oncology in Clinical Practice"[1].

Many medical professionals may feel a sense of embarrassment or even opposition upon digesting these two sentences, even though they come from a prestigious medical journal. Modern management of healthcare provider organizations has been promoted through training and organizational changes also in the Polish healthcare system for many years now. This is a result of practical consideration of the observations and insights of Michael E. Porter[2] and Avedis Donabedian[3] on the overall quality of healthcare.

According to Avedis Donabedian's classic theory, quality in healthcare can be considered and measured in three dimensions:

- structure (tools, resources, physical and organizational working conditions);
- process (actions, procedures, activities carried out by service providers and occurring between them and patients);
- outcome (health effect achieved, health status, patient's well-being and overall condition, etc.).

Value in health care can be defined as the quality of care as perceived by the patient (Fig. 1, numerator). Quality is affected by the results of the actions taken to benefit the patient by the medical staff and the efficiency of the processes as part of which the services are provided. The value equation can be a map to achieving a goal. Targeting actions at and focusing on the elements of value that the provider is able to control can result in significant improvements in the medical care provided.

In Poland, alongside the publicly funded healthcare system, an ecosystem of private healthcare providers has been developing rapidly. Donabedian's quality equation and the expectation of a "return on investment" are natural requirements set by corporate clients to providers like e.g. Telemedico.

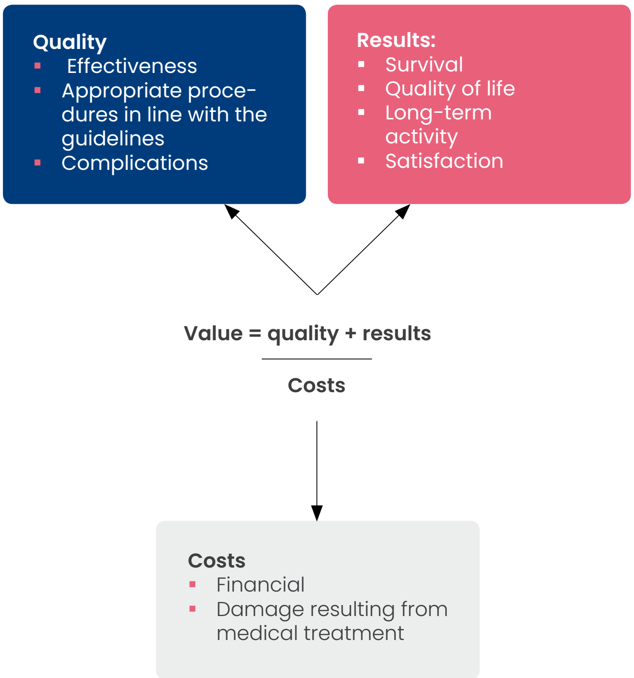



Fig. 1. Elements of value equation

## AI IN TELEMEDICO

Artificial intelligence was introduced to the market by Telemedicin sp. z o.o. (hereinafter referred to as Telemedico) – the largest (operating in 14 countries) provider of telemedicine services in Central Europe, which enables doctors from several continents to conduct over 100 thousand consultations a month – over 4 years ago. Currently, the company is using and developing AI tools to support two processes: *symptom checker* and diagnostic support.

*Symptom checker* analyzes the symptoms reported by the patient at the consultation appointment stage. Before the patient selects the specialty and suitable date of the consultation, the process of automated medical history begins, the results of which are then transferred to the Telemedico system in a convenient way for the patient. The patient receives feedback on whether the problem qualifies for a remote consultation or whether it should be looked into by a physician during an in-person visit at a medical facility.

Last but not least, artificial intelligence suggests the specialist the patient should be referred to so that their condition is accurately and quickly diagnosed and addressed.

There are two types of verification applied, divided into short and more in-depth interviews. The latter makes it possible to clarify, specify the problem and serves as an 'input' to the patient's medical record as an initial interview with the patient.

**Main advantages of *symptom checker*:**

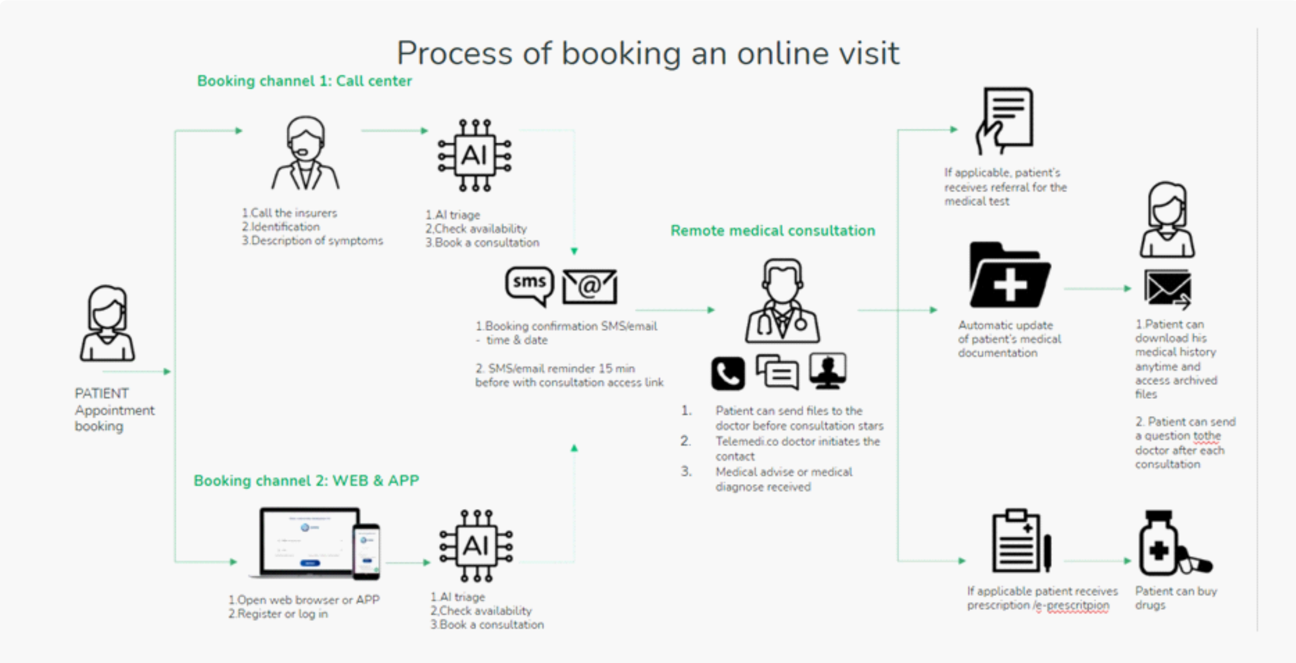
- streamlining the process/reducing the time involved in booking an appointment before a consultation;
- facilitating the process of booking of a relevant consultation with a medical specialist through an interactive "triage" form (a procedure used in emergency medicine that lets medical services sort patients requiring assistance according to the severity of illness or injury)[4], which is to make it possible to determine whether a given case or disease symptoms qualify for telemedicine (teleconsultation);
- suggesting the medical specialty which the patient should seek advice with on the basis of previously reported symptoms – the type of specialty appropriate to the set of symptoms collected as part of the "triage";
- "organizational learning" – the symptoms reported by patients, the assignment of the patient to a specialist, and the treatment results obtained allow for continuous process improvement.

Another purpose for which artificial intelligence is applied in Telemedico is to interactively assist the physician in verifying the patient's symptoms, making a diagnosis, and following medical recommendations for therapy. The Telemedico platform provides physicians with recommendations based on the symptoms reported by the patient. It also offers treatment advice or additional information about the diagnosis. This reduces the consultation time spent with the doctor by 22%. On average, doctors have now one more consultation per hour.

**The main advantages of the process of diagnosing patients by specialists:**

- suggesting disease entities that fit the set of information collected from the patient as part of the "triage" and in-depth medical history to medical specialists;
- suggesting medical recommendations that have the greatest impact on further treatment of the patient, including e-referrals, e-prescriptions, and other medical certificates;
- standardization of processes and procedures translates into better results and – at the same time – high efficiency of patient service.

The fact that each person using the platform individually determines the scope of medical data entered into the system and its wording may lead to a situation where the same data have different meanings. The performance of the algorithm and the quality of the prediction largely depend on the data which are gradually added to ('fed into') the platform. Hints offered to physicians support them in diagnosing the patient and filling in the documentation correctly. When a doctor disagrees with a prompt, they enter their own information, which is fed into the algorithm and then reviewed by other doctors for accuracy. Below follows an overview of the entire process of booking and attending a consultation with the use of artificial intelligence in Telemedico.



An important element to stress here is that the list of disease entities and symptoms used in the system also includes a description of what gender and age range the symptom/disease applies to.

The database includes a definition of the ranges of results of common tests to make it possible to determine whether a result is normal or below/above normal.

## STRUCTURE, PROCESS, OUTCOME

When it comes to the Polish health care system, the greatest weight is given to the first of the mentioned elements of Donabedian's quality theory – the structure[5]. This traditional approach stems from the ease with which measures can be established (e.g. considering the available medical devices or formal competencies of staff, i.e. specialization of physicians). In many countries, it is common to give more priority to the evaluation of the process and the outcome itself.

From a strategic perspective, process indicators translate into better health care management – they allow continuous quality improvement and are not, like outcome indicators, vulnerable to manipulation. Indeed, outcome measures which accurately measure medical interventions carry a serious risk of selecting patients admitted to the facility (the healthier the patients, the better their treatment outcomes) or abandoning interventions that involve a higher risk of failure[6].

Telemedico provides services in a B2B model, offering them to corporate clients. For instance, insurance companies are expanding their offerings to include medical services. Telemedico's 50 corporate clients are primarily insurance companies, including Allianz, AXA, Compensa, Metrored, PZU, and Tu Zdrowie. In Poland, Telemedico offers also consultations to patients as part of the primary healthcare financed by the National Health Fund[7]. Managing quality through processes and relying on artificial intelligence is key to building value for customers who are good with counting money (such as insurance companies). Launching the platform (offered in a *white-label* model[8]) for a new corporate client is expected to take an average of 48 hours.

The platform provides access to online medical consultations, a system for collecting and securing medical records, recording and organizing appointments, arranging medical examinations, as well as a tool for automatic triage and preliminary medical diagnosis.

Telemedico's corporate clients have access to a network of over 600 doctors speaking 10 languages (including Polish, English, Spanish, Portuguese, Russian, Turkish, and Arabic).

**TOMASZ JAWORSKI**

*(The author's profile is included in Chapter I.)*

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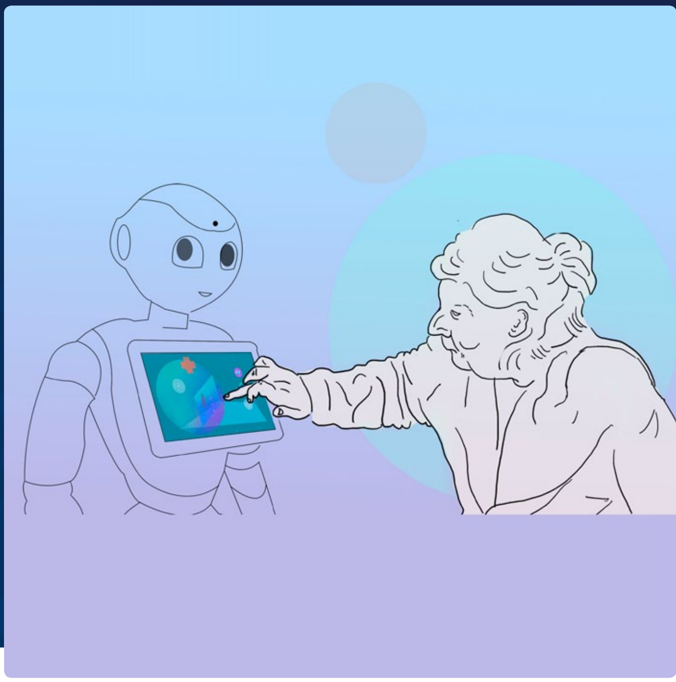
# Artificial intelligence in long-term care

ALICJA TURCZYK



## → Senior citizens currently taking advantage of long-term care are not generation smart, but it will change in the future

The community of people involved in the development of long-term care pins hope on the potential and utility of artificial intelligence in e.g. solutions used to **monitor patient condition**. Adequate and rapid assessment of the patient's condition is essential but currently hampered by staffing shortages in nursing and care teams. Assuming that staff shortages will continue to grow due to the current epidemic situation in Poland and the transfers of medical staff from e.g. the care sector to units preoccupied with the fight against Covid-19, it should be assumed that the adoption of solutions facilitating the work of long-term care professionals is highly desirable. It will, in part, replace the need for in-person monitoring and provide medics with knowledge of patient parameters. I have been following the development of smart technologies embedded in the beds and infrastructure of wards for the elderly with great interest. I hope to see a large-scale market adoption of not only simple features but also highly advanced functionalities collecting data about the patient and drawing conclusions needed by medical professionals to provide proper care and respond quickly to adverse events.

The current generation of senior citizens in long-term care is not a "smart generation". Artificial intelligence will not offer them a substitute for verbal interaction with another person, a physiotherapist, an occupational therapist, or a carer. However, **the generations to come will be increasingly bold in taking advantage of AI innovations** and find it easier to accept that it will be devices – not humans – that will support them in their daily functioning. I'm not advocating replacing people with artificial intelligence, but it's something worth preparing for, especially since long-term care is facing another challenge: providing senior citizens with the much necessary care in times of the pandemic and isolation. In parallel with the development of this thought, steps would need to be taken to apply artificial intelligence in the broad domain of **re-educating and compensating for functional limitations**. The way forward for the use of artificial intelligence becomes wide open in the field of both motor rehabilitation and rehabilitation/therapy of cognitive functions. Individuals begin to depend other people when they are no longer able to cope fully with their environment. If technological solutions could be developed to **replace lost functions and modify the environment so that the affected person can continue to cope with it**, the period of independence and autonomy of the senior citizen would be extended, and the need for long-term care would be significantly postponed, benefiting the senior citizen, their families and close ones, and the healthcare system as a whole.

**Alicja Turczyk, PhD** – Doctor of Physical Culture (PhD in Neurological Rehabilitation), graduate of Physiotherapy (University School of Physical Education in Krakow), Health Management (University of Warsaw), and Occupational Therapy. Development Director of the non-public healthcare center Pasternik Maluty sp.j., where she deals with identifying and implementing optimal solutions for long-term care and rehabilitation of the elderly and disabled. Co-owner of a primary healthcare center providing care to over 6,500 patients. Coordinator of infrastructure and social projects financed from EU funds. She offers consulting services to businesses, focusing on the advising on solutions aiming to optimize management activities in medical facilities and enabling carrying out research and development projects. Expert of the National Centre for Research and Development for evaluation of research and development projects in the field of prevention in the elderly, rehabilitation, and geriatrics. In 2016, she established the RehAaktywacja Foundation for Rehabilitation and Long-Term Care. She's currently the president of the board of the foundation.

Example of application

# The needs of senior citizens

Tomasz Jaworski

## → Providing effective medical care to nearly 10 million senior citizens, half of whom live outside of major cities, is becoming increasingly possible thanks to technology

Over 25% of our nation's citizens are senior citizens – people aged 60 and above. There are many good reasons for the needs of this group to be seen and considered seriously – from simple gratitude for what we owe to senior citizens to the political and economic potential of these needs. Somewhere among the various reasons to take note of the presence of seniors there are those concerning their healthcare needs and the nature of those needs.

It is therefore not surprising that seniors have been 'rewarded' with a special law[1] according to which every year the government makes an analysis of their current situation and of their needs and expectations[2]. The elderly benefit also from a relevant social policy[3], whose objectives are set for up to 2030 in three main areas: safety, participation, and solidarity. Getting seniors actively involved in community life is an initiative financed from the European Social Fund.

One of the characteristics of senior citizens is that they need effective, planned healthcare. In 2019, nearly two-thirds[4] of people aged 60 and over indicated that they had a long--term mentioned they had a long-term health problem or a chronic disease (i.e. lasting or expected to last at least 6 months). According to the survey, about half of seniors live in small towns (rural or small cities).

Providing effective medical care to nearly 10 million senior citizens, half of whom live outside of major cities, is a significant organizational and financial challenge. This challenge is increasingly being met thanks to technology.

### AN EFFECTIVE SENIOR CARE SOLUTION

Telemedycyna Polska S.A., Microsoft's partner, co-implements an EU-financed project called "W ochronie zdrowia i życia" ["To Protect Health and Life"] with the municipality of Częstochowa[5]. Medical and social care services are provided to 300 single senior residents (aged 65 and over) of Częstochowa. The initiative is a continuation of a very successful project named "Bezpiecznie we własnym domu – usługi teleopiekuńcze" ["Safe at Home – Telecare Services"]. It had ran from 2017 for two years. The beneficiaries were 200 inhabitants of Częstochowa. The project was appreciated not only by seniors themselves, but also by independent bodies. Two years ago, it was entered in the "Golden Book of Good Practices for the Social Participation of Older People" of the Polish Ombudsman's Office[5].

The project involves screening and offering support in the area of the most common conditions typical of senior citizens: cardiology, diabetes, neurodegenerative diseases (risk of Alzheimer's or Parkinson's), and remote psychological counseling. The ICT equipment provided by Telemedycyna Polska S.A. enables 24/7 contact with remote care workers, who are there to help in case of life and health threats, but also in case of increased stress, anxiety, or a sense of loneliness. A medical professional analyses the situation remotely, supports the person under their care, and automatically contacts emergency services or the support network established as part of the project (neighbors, carers, family members, a nurse, or the relevant healthcare center).

There are more similar senior care projects, such as the pilot project run in Wrocław for 110 senior citizens. It consists of a cardiology, diabetes, and senior telecare package. Cardiac patients receive a portable ECG device (medical product) connected to a telemedicine center that monitors the recordings from the device 24/7. ECG examination can be initiated by the patient themselves and performed in an unlimited number. Also, the result of the examination can be consulted each time with the telemedicine center. The package is primarily used by seniors with arrhythmia because in their case, the frequency of testing is very important[6].

It appears that it is possible to fulfill the needs of the large group of senior citizens thanks to the appropriate use of technology, the right organizational solutions, and the planning of the process of service provision in such a way as to enable cooperation between medical professionals of different specializations, logisticians, and telecenter staff. Electronic sensors (e.g. a cardiac holter monitor), working 24/7, provide massive amounts of data that could compromise project goals – if not for artificial intelligence.

## AI: ADDITIONAL, TIRELESS STAFF

With the increase in the number of provided services, Telemedycyna Polska S.A. sees a high potential in modern technologies based on the analysis of medical data with the use of AI. The company continually monitors the market for new sensors that can provide clinically relevant information from the patient's home, as well as for the software to analyze medical data. According to the information it has obtained so far, the main driving force in the development of telemedicine in the years to come will be data science. With the huge amount of incoming data and the great potential benefits of evaluating these data quickly, it is crucial to make it possible for telemedicine centers to use artificial intelligence algorithms.

At present, AI algorithms are being implemented following all the relevant precautionary measures to enable initial automatic classification of heart rhythm based on ECG recordings and algorithms to detect non-assessable tests.

This enables a much faster analysis and description of ECG examination, which translates into a lower final cost of telemonitoring, as well as the ability to provide care to many more patients in the same amount of time. As a result, a doctor or a paramedic will be able to respond much faster to alarming test results and will not have to spend time dealing with tests whose results have been e.g. distorted by the patient's movement.

"The first area that will be supported in this way is the healthcare programs we run for individuals and medical facilities. Supporting remote care with artificial intelligence algorithms will let us significantly increase the number of people provided with care while maintaining the necessary level of safety. Another area where we plan to use pre-automated heart rhythm classification is the screening programs we organize, where the use of such a system will allow us to screen many more people." – says Mikołaj Basza, Board Advisor for New Technologies at Telemedycyna Polska S.A.

The company processes massive amounts of data which are to be used to further automate patient care processes. The data in use come from a variety of devices and systems, and much of them are unstructured. Structuring the data, structuring the text data, and labeling the data makes it possible to use the data to train machine learning models. Given the nature and type of data, this is a complex process that requires the collaboration and involvement of data analysts, IT professionals, and medical specialists. NER (*named entity recognition*) and NLP (*neuro-linguistic programming*) play an important role in the process of structuring large amounts of textual data. However, the ultimate justification for all these initiatives can only be the quality of the services provided and their affordability – in other words, finis coronat opus: the goal is the good of the patient.

→ **Thanks to the use of ready solutions and libraries that enable the automation of data labeling, as well as to the collaboration with experts and use of Microsoft technologies, it is possible to carry out the necessary work faster and cheaper. However, the ultimate justification for all these initiatives can only be the quality of the services provided and their affordability – in other words, finis coronat opus: the goal is the good of the patient.**

**TOMASZ JAWORSKI**

*(The author's profile is included in Chapter I.)*

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# Practical use of Artificial Intelligence in oncologic surgery

JOANNA SZYMAN

→ **Today, what is at stake in cancer research is to turn a deadly cancer into a chronic disease**

→ **AI and medical robots are bringing a Copernican revolution to the domain of healthcare**

Before the outbreak of the COVID-19 pandemic, the list of challenges faced by the health sectors of developed countries was already long. The most common problems included: aging population, shortage of medical staff, inequalities in access to medical care, and the increasing costs of medical care.

These problems can be found occurring all at the same time in oncology. Cancer is a global phenomenon similar in nature to the coronavirus pandemic. Europeans make up less than 10% of the world's population, but Europe accounts for a quarter of all cancer cases.

This fact clearly illustrates how great a threat cancer is to our society. The cost of the economic impact of cancer on Europe's economy is estimated to amount to €100 billion per year. In Poland, cancer is the second cause of death – and will become the first within the next few years. Meanwhile, up to 40% of these deaths could be avoided if the diagnosis was made earlier or the patient had better access to the latest treatment methods. That is why Europe's Beating Cancer Plan was created. It will be implemented using the full range of European Commission's funding instruments, amounting to €4 billion. The tools supporting fighting cancer will include solutions utilizing artificial intelligence. Making practical use of AI in medicine brings a change comparable to the Copernican revolution. Computer modeling of intelligent behavior with minimal human intervention, artificial intelligence algorithms, and *deep learning*, which create information classification criteria on their own based on data acquired in the programming process, can be used in each of the four areas defined as priorities in the fight against cancer:

- **cancer prevention**, vaccinations, stimulation of health-enhancing behaviors, and elimination of risk factors;
- **early detection** of cancer;
- **diagnostics and treatment** through activities aimed to provide more integrated and comprehensive cancer care, cancer imaging initiatives, and support for personalized medicine solutions;
- **improving the quality of life** of cancer patients and survivors, including rehabilitation and measures to promote social and workplace integration[1].

As more data are provided, systems become more precise and accurate, and benefit from an increasingly extending scope of analytics. The key arguments speaking in favor of an AI-based technology revolution in medicine are that algorithms help make decisions faster and don't allow emotions to influence judgment or the quality of the procedures performed. The outcome can be higher accuracy of procedures and fewer medical errors made. The use of artificial intelligence means also better drug selection, more effective e-therapies, more successful disease prevention, and reduced medical costs[2].

## TELEMEDICINE AND HEALTH MONITORING SUPPORTED BY AI ALGORITHMS

The most popular form of using artificial intelligence is solutions utilized in the domain of telemedicine.

→ **U.S. research firm Global Market Insights predicts that the global telemedicine market will grow nearly 20% annually by 2026[3].**

The most popular form of application of AI in this area enables patients to contact healthcare facilities using solutions supported by AI. At NEO Hospital, we utilize online consultations in the pre-qualification process for oncology treatment, after we obtain diagnostic data beforehand. Another – more advanced – form of this service is the remote monitoring of patients' condition using certain specific devices. One example is CarnaLife System's technology designed and used to securely collect medical data and record test results in real-time in the Azure cloud and interpret them using artificial intelligence algorithms. A significant role in the field of oncology is played by teleradiology and the ability to remotely contact and process image data.

## SMART TECHNOLOGY FOR 3D VISUALIZATION OF MEDICAL IMAGE DATA

Another solution making use of artificial intelligence is tools for planning complex procedures, such as the CarnaLife Holo system. Thanks to the adoption of this system at NEO Hospital, we're able to perform oncological procedures in the area of unresectable primary liver tumors. The system makes it possible to analyze the patient's image data both in classical view and in the form of a three-dimensional visualization in different modes. It is possible to access data and visualizations at every stage of treatment, both during the planning of the procedure and when it is performed. The technology allows the operator to accurately visualize and locate lesions, which increases the safety and shortens the duration of the procedure, and makes it possible to perform a targeted procedure.

→ **NEO Hospital makes use of the CarnaLife Holo 3D medical image data visualization technology also when conducting a research and development project in gynecologic oncology.**

Its aim is to develop a new method of surgical treatment of endometrial and cervical cancer.

The said research and development program conducted in the field of gynecological oncology is a project that is unique in Poland – it is the first ever commercial research project carried out in the field of robotic surgery in our country. The project involves performing 200 surgeries with the use of the da Vinci system. Cancer R&D is badly needed to transform cancer from a fatal disease into a chronic one. Medical innovations, scientific discoveries, and new therapies in this field can let patients live a longer life.

## SURGICAL ROBOTICS – UNIQUE POTENTIAL TO IMPLEMENT AI-BASED SOLUTIONS

The engagement of surgical robots in the field of oncological surgery is a real breakthrough, creating new potential for the implementation of solutions based on artificial intelligence. Robotic surgery was one of the fastest growing branches of medicine in the world even before the pandemic broke out[4]. According to data presented at the J.P. Morgan Healthcare Conference 2021, there were more than 1.2 million surgeries performed with the da Vinci robot in 2020. A total of 8.5 million such operations have already been performed worldwide. The number of systems already in clinical use is now over 6,000. It is important to mention that the share of facilities using more and more systems in one location is growing dynamically. In global terms, the share of such facilities (i.e. using 7 and more such systems) has reached 20%.

The Polish market also sees a quality revolution in the field of surgery taking place, and our hospital is strongly involved in this phenomenon. At NEO Hospital, we use a da Vinci robot in urological, gynecological, and surgical procedures. In 2020, despite COVID-19, the number of surgical procedures performed with the assistance of a robotic system nearly doubled compared to the same period a year before.

At present, the da Vinci robot is the most popular surgical system in the world. Surgeries and procedures that once required large incisions and weeks of recovery are now minimally invasive, more precise, and allow patients to return to normal life much quicker.

At Neo Hospital's Robotic Surgery Center, we use the fourth generation da Vinci X robotic system, which helps streamline the surgeries performed.

The first enhancement is a telemetry system that enables the remote control of surgical instruments. The surgeon works in a comfortable, ergonomic position behind the console. Another element is the vision system, which allows the image from the camera fixed on the robot's arm to be transmitted to the operator. Using the latest technology, it is

**Surgical system with robotic arms**
Robot arms equipped with surgical micro-instruments, designed to mimic the movement of human hands, wrists, and fingers, enabling the surgeon to perform a wide range of movements with greater precision.

**Console**
A console (control unit) that lets the surgeon control the operation (motion) of instruments by translating their own natural hand and wrist movements into appropriate precise and scaled robotic arm movements.

**3D camera**
A 3D camera providing the surgeon with a 3D view of the surgical field, including depth of field, over 10x magnification, and high resolution. The da Vinci system translates every hand movement performed by the surgeon into an image displayed on the screen - in real time.

possible to use 3D imaging in HD quality and modulate the depth of the operating field, which gives the operator the ability to very accurately distinguish the anatomical structures on which the surgery is performed. The endoscope camera offers a 10x optical zoom and a 4x digital zoom. The da Vinci X surgical robot has four universal arms that allow changing surgical instruments according to the stage and type of the surgical procedures performed. They let the endoscopic camera to be repositioned for a more accurate observation of the workspace and the viewing angle to be determined according to the needs of the operator[5].

A very important element of the system is the EndoWrist technology, which substitutes the surgeon's hand during surgery[6]. EndoWrist provides several times more range of motion than its biological counterpart, and has seven degrees of freedom (a variable that makes it possible to describe the position of the object) – whereas the human wrist has only three.

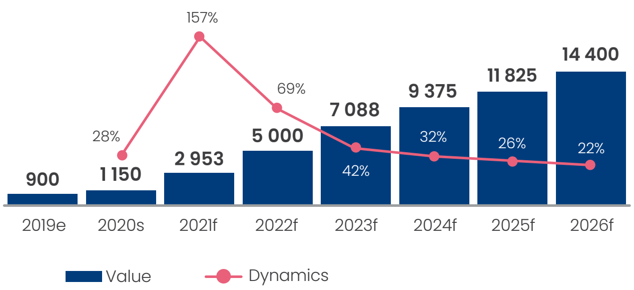
## INCREASING COMPETITION IN THE ROBOTIC SURGERY MARKET

Intuitive Surgical, the manufacturer of the da Vinci robot, invests huge amounts in research and development each year. In 2019, it was $557.3 million, which was 32% of the company's total operating expenses. Intuitive Surgical has established a dedicated innovation fund, Intuitive Ventures, with $100 million to invest in digital tools, precision diagnostics, focal therapy, and technology.

However, Intuitive Surgical can already see some serious competitors in the market, including Medtronic and a consortium of Johnson & Johnson and Google, who are working on their own robotic systems. Acquisitions are also underway in the sector of solutions relevant to the growth of the surgical robotics market. In February 2020, two major players announced acquisitions of smaller medical companies[7]. The market leader, Intuitive Surgical, bought Orpheus Medical, a developer of a platform for storing and archiving recordings of surgical procedures[8]. There is also Medtronic, listed on the Dublin stock exchange market, who announced the acquisition of the British True Digital Surgery – the creator of the Touch Surgery interactive surgical simulator. Medtronic believes this move will accelerate its development of a soft tissue surgery robot.

## THE SIZE OF THE ROBOTIC SURGERY MARKET AND THE GROWTH FORECASTS FOR POLAND

According to estimates based on a survey conducted for the PMR Market Expert and Upper Finance Group report, there should be about 40-50 robots in a country the size of Poland.




*e - estimate*
*f - forecast*

Fig. 1. The number of procedures and the dynamics in the surgical robotics market in Poland, 2019-2026. source: Upper Finance, PMR, 2021

Given the degree of market development, the way healthcare is financed, and the macroeconomic conditions, we can expect to have a total of around 40 systems in use by the end of 2025[9]. An important thing to mention here is that the market dynamics would be even higher if the Polish National Health Fund launched a separate program to finance these procedures.

### THE BOOM IN ROBOTIC MINIMALLY INVASIVE SURGERY IN THE AGE OF CORONAVIRUS

The pandemic has clearly emphasized the importance of the values associated with minimally invasive surgery. It has made hospitals change the way in which they usually operate – and consider new values. One of the key elements of safety is now the possibility to reduce the length of time a patient is hospitalized and the involvement of bed infrastructure, particularly when it comes to intensive care. In this context, the following values of minimally invasive surgery become especially significant:

- greater precision and shorter duration of surgeries;
- reduced surgical trauma (small incisions, faster wound healing, less postoperative pain, less blood loss, and – most importantly – less risk of infection);
- shortened time of hospitalization, limitation of complications, faster convalescence.

### A NEW MODEL TO EDUCATE SURGEONS WITH THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence can help address the problem of medical workforce shortage by offering e.g. a change in the model of staff training. The development of AI has led to the emergence of many dedicated training centers, where simulators (similar to those used in aviation) make it possible to perform virtual surgeries and simulate the various stages of the procedure – including complications. Such a model shortens the learning curve, but also allows for standardization of the process and offers a better preparation for practice. This translates directly into benefits for patients.

**JOANNA SZYMAN**

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Example of application

## Oncology diagnostics

Tomasz Jaworski

### → Today, artificial intelligence is being implemented in five areas of oncology

The first thing that comes to mind when thinking about the use of artificial intelligence in medicine is usually image recognition. And the 'icon' of diagnostic imaging for patients is an X-ray image – like from a chest X-ray. Indeed, almost half of the patents[1] in the area of artificial intelligence in the world today concern automatic image processing. An algorithm can detect and pre-identify lesions "looking at" any image – X-ray images, video recordings from endoscopic cameras, CT images, microscopic images of histopathological preparations, etc. Many Polish partners, who offer highly advanced solutions of the highest quality on a global scale, deal with the application of AI in this type of tasks.

## THE GOAL: TO MAKE CANCER NON-FATAL

Cancer is the second most common cause of death in Poland. The most common cause of oncological death in the country is, in turn, lung cancer – there are almost as many deaths (46%) as there are deaths reported for the next three most common cancers together: colorectal, breast, and prostate (49% in total). If the time required to detect cancer could be shortened, it could be now a chronic disease rather than a fatal one[2].

According to the authors of the report "Innovative Oncology. Needs. Capability. System", developed under the scientific editorship of Barbara Więckowska and Adam Maciejczyk[3], an innovation which can significantly contribute to the improvement of therapy effectiveness and patients' quality of life is a better organization of Polish oncology as a whole. The authors point to 5 priorities:

**Priority 1** – Coordinated Healthcare,
**Priority 2** – National Cancer Strategy,
**Priority 3** – selecting a treatment and care coordinator,
**Priority 4** – psychological and social support,
**Priority 5** – oncology rehabilitation,
where artificial intelligence and identification of information in huge data sets (Big Data) are applied to coordinate activities and make data-driven decisions.

In order for early detection of any cancer to be possible, it is necessary to reduce delays in the so-called patient pathway. This means organizing patient care in such a way that the following elements work together, like in a fine-tuned orchestra:

- **patient awareness** – avoiding risky behavior (e.g. smoking) and following doctor's recommendations,
- **preventive examination** covering the widest possible population of persons at risk (e.g. genetic tests to detect any genetic predispositions),
- patient-tailored care **offered by primary healthcare centers** (standardized medical history based on questionnaires, population stratification, and division into regular check-up/follow-up groups, individual care plans, balance sheets),
- **specialist care** – diagnostics and therapy offered at specialist centers with access to advanced technologies.

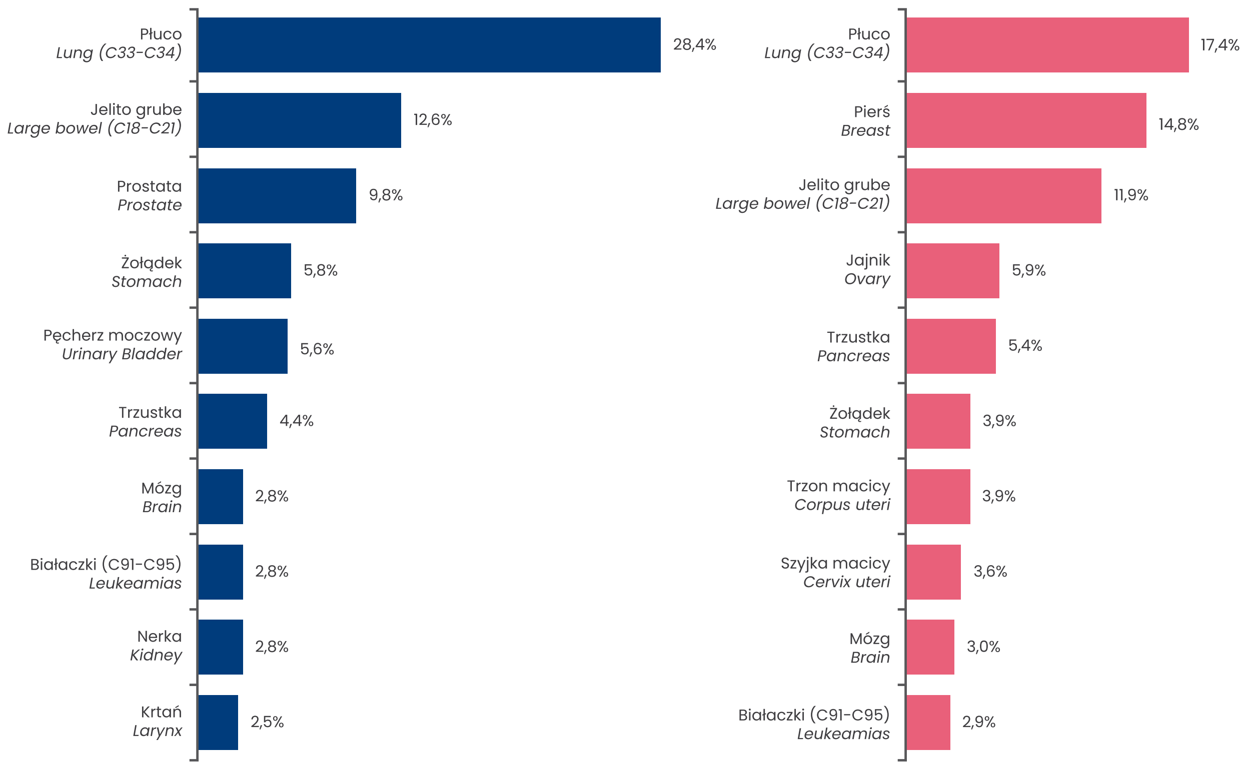



Fig. 1. Structure of deaths from malignant neoplasms in Poland, 2017

The figure below shows the various steps in the process where delays can occur.

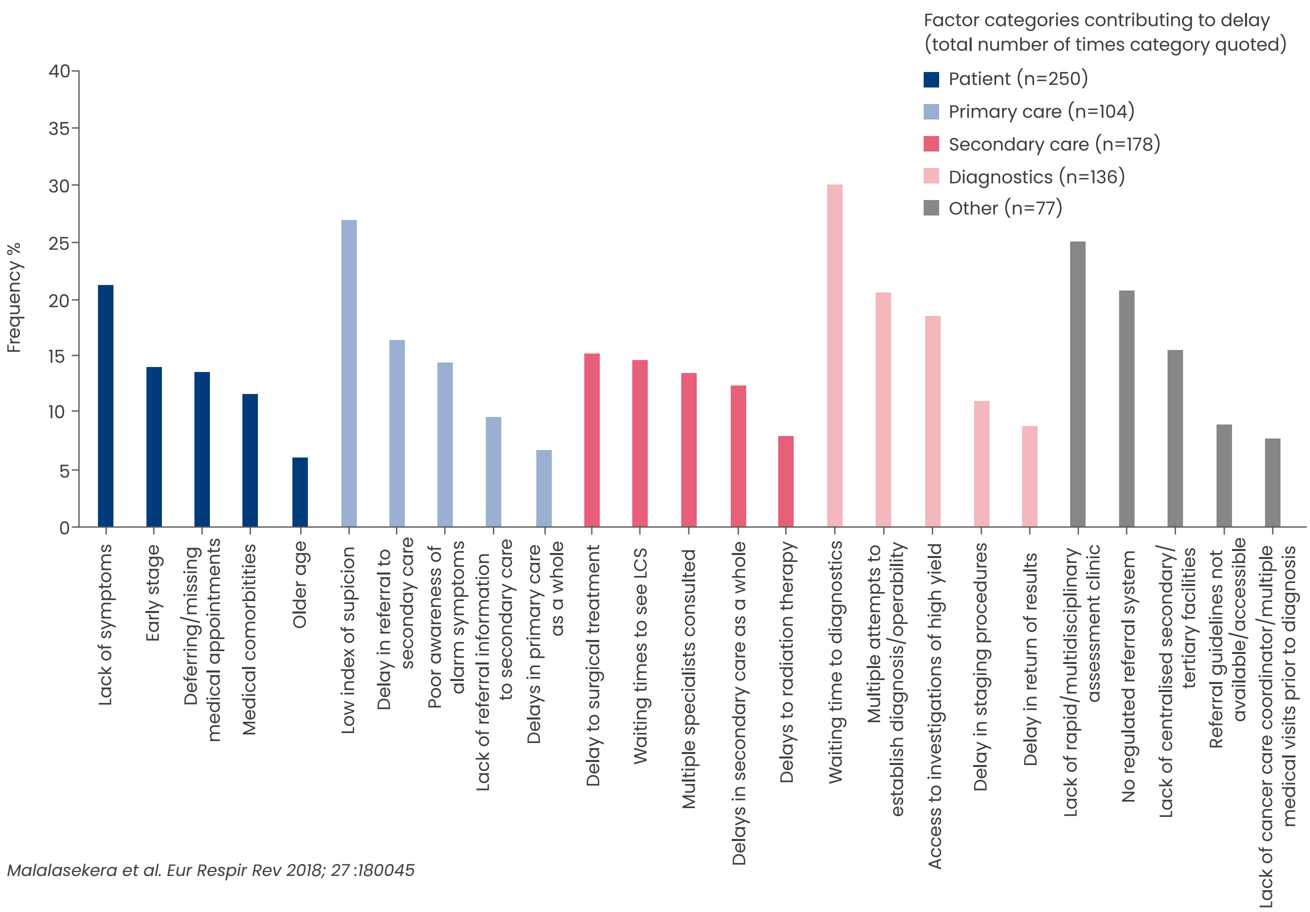
### From analysis to decision

Examples of artificial intelligence implementations in oncology span several areas. One of them is to support rapid analysis of data collected with the use of so-called *symptom checkers*. However, it is not an easy task when it comes to the analysis of such a history in the context of the abovementioned 15 types of the most common fatal cancers in Poland.

→ **The second area of implementation of AI in oncology is the domain of support of diagnostic imaging. In the POZ+ project, a solution based on ML and *deep learning*, developed by the Polish company Digitmed, has been used to increase the availability of preventive gynecologic cytological examination and to improve the quality of cytology evaluation.**

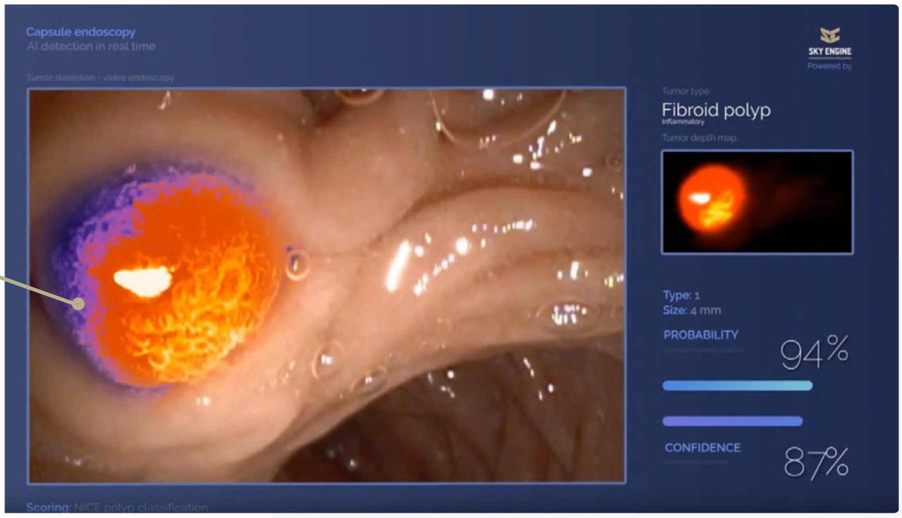
A Microsoft Research grant awarded to the Adam Mickiewicz University in Poznań made it possible to carry out a project named OvaExpert, which makes it possible to support the physician in the process of prognosis of the malignancy of ovarian tumors. SkyEngine's solution detects and recognizes lesions in capsule endoscopy recordings, reducing the time required by the physician to properly evaluate diagnostic material even 18 times (from 3 hours to 10 minutes). Wherever the use of AI can improve the speed of diagnosis, the necessary tools are already at an advanced stage of development – the most advanced example being Microsoft InnerEye[4].

The third area is care coordination – the key role here is played by coordinators who are to contact patients to make sure that they are not "left outside the system". The subsequent steps of diagnosis should be proceeded with as soon as possible. What is absolutely necessary at this stage is a modern *contact center* (hotline, chatbots, voicebots, speech-to-text, conversation scenarios) with a current schedule allowing appointments to be made at the relevant diagnostic facilities. It's an essential element – one whose absence is shown clearly in the statistics. The current method of coping with the lack of such a systemic solution has been the 'cancer diagnosis and treatment' card (commonly called the DILO card), which acts as a fast-track pathway in cancer therapy. Artificial intelligence can help take the next step here.




*Malalasekera et al. Eur Respir Rev 2018; 27 :180045*

Fig. 2. The importance of factors that delay diagnosis and treatment




Sky Engine AI cancer detection on real-time endoscopy video

## Synthetic intestines

The fourth area of oncology where artificial intelligence is applied is 3D imaging. Many Polish companies provide solutions making use of Microsoft HoloLens augmented reality goggles, which allow doctors and patients to work with a 3D model of organs and anatomical structures. It enables scheduling procedures, holding remote case conferences, advanced learning, and even reduces patient stress by allowing the doctor to present and discuss the planned procedure in an understandable way.

The fifth area of application of AI in oncology is the use of data by physicians–decision-makers for strategic and operational decision-making. Microsoft PowerBI software features AI-based mechanisms for retrieving and loading data from different hospital systems. AI also enables the creation of quick summaries and data visualizations – in line with the claim that "one picture is worth a thousand words". This area of data-driven decisions covers also the ongoing work focusing on the use of data on a variety of population factors correlated with lifestyle, food quality, and environmental resources to better target oncology prevention programs.

**TOMASZ JAWORSKI**

*(The author's profile is included in Chapter I.)*

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## Use of AI in Health Technology Assessment (HTA)

**Justyna Ożegalska-Trybalska**

Artificial intelligence (AI) can be a strategic tool to improve the accessibility, quality, profitability, and efficiency of healthcare systems, particularly thanks to the use of *Health Technology Assessment* (HTA). In this multidisciplinary process that summarizes information about the medical, social, economic, and ethical issues related to the use of a medical technology, it is critical to process the information required to develop safe and effective health policies. Appropriately designed AI technologies can support making such assessments in a systematic, transparent, unbiased, and reliable manner. In consequence, they can assist in making decisions regarding the selection of the most valuable technologies to invest in for the benefit of the healthcare as a whole and concerning the optimal use of resources allocated for this purpose. This is of grave importance for the operation of healthcare systems worldwide, increasingly overloaded and even inefficient as a result of the combat against the COVID-19 pandemic. In order to make good use of AI in health technology assessment, it is necessary to create not only the necessary technological conditions for innovation in this field, but also the necessary regulatory and legal conditions – including in the field of intellectual property law. The discussion and the future legislative initiatives should address several issues. First, it is important to consider a fast-track patenting of AI used for healthcare or health technology assessment purposes. Second, it is necessary to provide for a research exception related to the assessment of medical technology utilizing AI, which would make it possible to avoid unnecessary investments of time and money in identifying patents that may be infringed in connection with research and technology assessment.

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## Artificial intelligence in medical devices

### Magdalena Wicher

Artificial intelligence in medical devices is a relatively new technology – and one that is constantly evolving and poses a major challenge to regulators. EU directives and regulations (e.g. MDD[1], MDR[2]) and harmonized standards (e.g. PN-EN 62304:2010/A1:2015-11) do not have specific guidelines for medical devices that feature or utilize AI and/or ML. In contrast, the existing general regulatory requirements for such devices address the following matters:

- demonstration of the safety and performance of the medical device (classification rules established in the form of Annex VIII to MDR). The manufacturer needs to bear in mind that the class of a medical device determines its safety class, and the use of AI will certainly increase this class;
- devices must be validated against the intended purpose and requirements and verified against the specifications (MDR, Annex I 17.2);
- they must ensure that the software featured has been developed in a manner that guarantees repeatability, reliability, and performance (MDR, Annex I 17.1);
- if the clinical evaluation is based on a comparable device, the device must be sufficiently technically equivalent, which explicitly includes the assessment of software algorithms (MDR, Annex XIV, Part A, item 3);
- manufacturers must carry out and update a risk analysis in accordance with PN-EN ISO 14971:2020-05 and the ISO/TR 24971:2020 guide;
- manufacturers must identify and ensure the relevant competence of the people involved before developing the documentation (PN-EN ISO 13485: 2016-04 7.3.2 f).

A very important aspect in this context is also the security of the research whose results are stored in the cloud. In addition to the said regulations, the requirements of ISO / IEC 27018:2019 – Information technology – Security techniques – Code of practice for protection of personally identifiable information (PII) in public clouds acting as PII processors should also be mentioned here. This document sets out guidelines based on ISO/IEC 27002, taking into account the regulatory requirements for the protection of personal data, which may apply in the context of the cloud provider's information security risk environment(s) [1],[2],[3].

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[3] *ISO – International Organization for Standardization* – the text refers to the standard's number and scope: ISO / IEC 27018: 2019 [original title: *Information technology — Security techniques — Code of practice for protection of personally identifiable information (PII) in public clouds acting as PII processors*] and ISO/TR 24971:2020 [original title: Medical devices – Guidance on the application of ISO 14971].

# Chapter III.

# AI in research and development – prospects for EU and national funding

KAMIL KLEPACKI

→ **EU structural funds and framework programs provide funding for many activities involving the use of AI in the health sector**

→ **The adopted AI policy and the financial perspective 2021-2027 point to a systematic increase in R&D spending – also in the health sector**

## INSTRUMENTS TO FINANCE AI FROM EU AND NATIONAL FUNDS IN POLAND

### 1. AI STRATEGY FOR POLAND

The Council of Ministers adopted a resolution on 28 December 2020, which established a policy for the development of artificial intelligence in Poland from 2020 (hereinafter referred to as the "AI Policy")[1] and defined e.g. the sources of AI funding. In this regard, the AI Policy implies that due to the small number of large private companies, it is necessary to involve also the public sector and the biggest state-owned enterprises in the financing of AI projects. The AI Policy also lists major public programs to support the development of innovation – including innovation in the domain of artificial intelligence[2]. Such programs include e.g. "Doktorat Wdrożeniowy II – sztuczna inteligencja" ["Implementation Doctorate II – Artificial Intelligence"], organized by the Ministry of Science and Higher Education and set to support scientific activity focusing on the use of artificial intelligence in technological or social processes. There are also programs run by the Polish Development Fund (e.g. PFR Starter FIZ, PFR Otwarte Innowacje FIZ), which include support for *venture capital* funds investing in modern technologies at both early and later stages. These programs make it also possible to offer support to the development and practical application of AI in the healthcare sector.

In addition to national resources, one of Poland's goals is to actively lobby for AI funding to be included in the European Union's Multiannual Financial Framework (financial perspective) for 2021-2027. It is reasonable to stress at this point that the European Union distributes funds through e.g. its structural funds and framework programs. The money offered through structural funds is allocated by the relevant competent institutions at Member State level. The funds granted under framework programs, in turn, are allocated at the central level of the European Union. In its AI Policy, Poland has undertaken to request that separate instruments supporting research and implementation of AI be included in the Cohesion Fund, the European Regional Development Fund, the European Social Fund Plus (structural funds), and the Digital Europe, Horizon Europe, and Connecting Europe programs in the area of telecommunications (framework programs). Poland has also committed itself to supporting the creation of separate, dedicated financial mechanisms to support the development of AI in Member States[3]. The abovementioned programs make it also possible to finance projects focusing on the development and implementation of AI in the healthcare sector.

**2. MULTIANNUAL FINANCIAL FRAMEWORK 2021-2027**

The European funds budgeted for the years 2021-2027 amount to around EUR 76 billion, which are to be allocated for investments in innovation, entrepreneurship, digitization, infrastructure or e.g. environmental protection. Like in the case of the 2014-2020 period, in the new financial perspective (MFF), 60% of the cohesion policy funds are to be allocated to programs implemented at national level. The remaining 40 percent is to be spent on regional programs[4]. At national level, funds are to be distributed under the following programs: European Funds for a Modern Economy (FENG), European Funds for Infrastructure, Climate, Environment (FenIKS), European Funds for Digital Development (FERC), European Funds for Eastern Poland (FEPW), European Funds for Social Development (FERS), Technical Assistance for European Funds, and the Fair Transformation Fund.

**3. NATIONAL SMART SPECIALIZATIONS**

An important aspect in granting EU funds is a list of specific industries included in National Smart Specializations (NSS; Krajowe Inteligentne Specjalizacje – KIS)[5]. These industries have priority in the allocation of the said funds. When drawing up an application for co-financing under a given measure, it is reasonable to see whether the proposed project focuses on investments in research, development, and innovativeness (R+D+I), i.e. in areas with the greatest innovative and competitive potential in the country, because these are the areas preferred when it comes to allocating European funds under particular programs.

**4. EUROPEAN FUNDS FOR A MODERN ECONOMY (FENG) AND EUROPEAN FUNDS FOR INFRASTRUCTURE, CLIMATE, ENVIRONMENT (FENIKS)**

The FENG funds are expected to support innovative R&D projects carried out under e.g. the NSS "Healthy Society". This specialization focuses on new products and technologies such as e.g. research on new therapies for civilization diseases, based on innovative technologies of personalized medicine (from the field of genomics, transcriptomics, epigenomics, proteomics, metabolomics). These are also projects dealing with the development of public R&D infrastructure in the area of health, carried out by research organizations, including medical universities, and cover e.g. research into innovative use of stem cells, progenitor cells, or other cells or tissues. The FENG funds are to support start-ups offering solutions in the area of healthcare (e.g. modern technologies and medical products). The innovative solutions developed for the healthcare sector in this way may then be promoted under FEnIKS, in projects involving e.g. the purchase of highly specialized medical equipment used for diagnostic, treatment, or rescue purposes. This shows the complementary character of the FENG and FEnIKS programs – in the thematic area of "health", among others[6].

**5. European Funds for Digital Development (FERC)**

The goal of the FERC program is to make the digital transformation of Poland successful and as far reaching as possible. The expected interventions include also those related to the use of artificial intelligence in the healthcare sector. The activities carried out under FERC's priorities, which include advanced digital services, will include providing high-quality and accessible public e-services – including e-health projects. The intervention will address the development and optimization of e-services for citizens and the implementation of innovative solutions in healthcare, which are to include those utilizing artificial intelligence and big data sets. Support will also be provided to investment projects focusing on the development of electronic medical records and telemedicine, as well as projects aimed at creating a coherent and efficient information architecture in the healthcare system[7].

**6. Other programs**

The activities which will enable supporting projects dealing with AI in the healthcare sector can also be found in other programs. Within the framework of FERS, funding will be available to initiatives involving e.g. analysis of the feasibility of the use of artificial intelligence in the area of a given examination and provision of digital accessibility, development of digital accessibility tools based on problem and solution analysis, and AI-based user support[8]. It will also be possible to receive EU funding under the framework programs mentioned earlier (e.g. Horizon Europe for research and innovation) or regional operational programs, adopted by the boards of all Polish provinces (each province, like in the 2014-2020 financial perspective, will have its own program). Regional Smart Specializations will play a big part here (each province, as it is now, will have a separate list in this respect).

The individual structural programs will be managed by the relevant managing authorities or designated intermediate bodies for European expenditure of EU funds[9]. Detailed information about a given program, the possibilities of project co-financing, the necessary documents or the rights and obligations of a beneficiary will be available, among others, on the websites of these institutions. It remains to be hoped that the presented AI financing instruments will attract great interest, which will in turn directly translate into the development of the healthcare sector in this domain. One of the most urgent systemic needs, the financing of which should be considered on the basis of the available EU funds for research and development, is the creation of properly secured clinical databases – examples of such databases[10] can be found in leading medical facilities around the world. The establishment of this type of infrastructure will make it possible to conduct research in Poland in accordance with the so-called 10x rule[11].

**KAMIL KLEPACKI**

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3. *Ibidem*, pp. 21-22.
4. Cf. information available at https://www.funduszeeuropejskie.gov.pl/strony/o-funduszach/fundusze-na-lata-2021-2027/dowiedz-sie-wiecej-o-funduszach-europejskich-na-lata-2021-2027/
5. These are set out in the Enterprise Development Programme developed by the Ministry of Development and adopted by the Council of Ministers on 8 April 2021. (the latest update is dated January 2021 and is available at https://smart.gov.pl/images/Opisy_KIS__werja_6_FINAL_01012020.pdf. It is assumed that they will retain their current form in the new financial perspective 2021-2027. Regional Smart Specializations (RSS) are determined at the level of individual provinces. They are instruments supporting the achievement of objectives of Regional Innovation Strategies for a given province.
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Example of application

# Rescuing young patients

Tomasz Jaworski

## → In the coming decade, the use of genomic information will become central to clinical decision support and healthcare provision

At St. Jude Children's Research Hospital in the U.S., there is an advanced research project underway, combining DNA sequencing with analysis of phenotypic data (i.e. observed body and health characteristics of patients). Thanks to the use of advanced technology provided by Microsoft and its partner company DNAnexus, it is possible to search for effective therapies and diagnostic methods that allow doctors to fight childhood cancers.

St. Jude Children's Hospital collects high-quality clinical and genetic data on pediatric diseases for this purpose. The hospital's data cloud now contains e.g. 10,000 complete DNA templates (whole genomes, exomes, and RNA sequences) of cancers and other serious childhood diseases.

Since the launch of St. Jude Cloud in 2018, more than 50,000 researchers from around the world have used the platform, including more than 1,000 registered users from 49 institutions in 15 countries. These research efforts have already had a positive impact on helping children with rare diseases.

The relationship between an organism's genetic characteristics (genotype) and observed traits (phenotype) is very complex[1]. The research dealing with this relationship is very promising, which is why it is also undertaken as part of EU-funded projects and at leading institutions in Poland – genomics is the basis for the development of targeted therapies and precision medicine. The advances in the field of DNA sequencing technologies have led to a revolution in genomics-based research and help to improve the general understanding of human biology and the mechanisms of disease development. This expanded knowledge leads to the proliferation of personalized medicine strategies to prevent, diagnose, and treat diseases. In the coming decade, the trend will continue because the use of genomic information will become central to clinical decision support and healthcare provision.

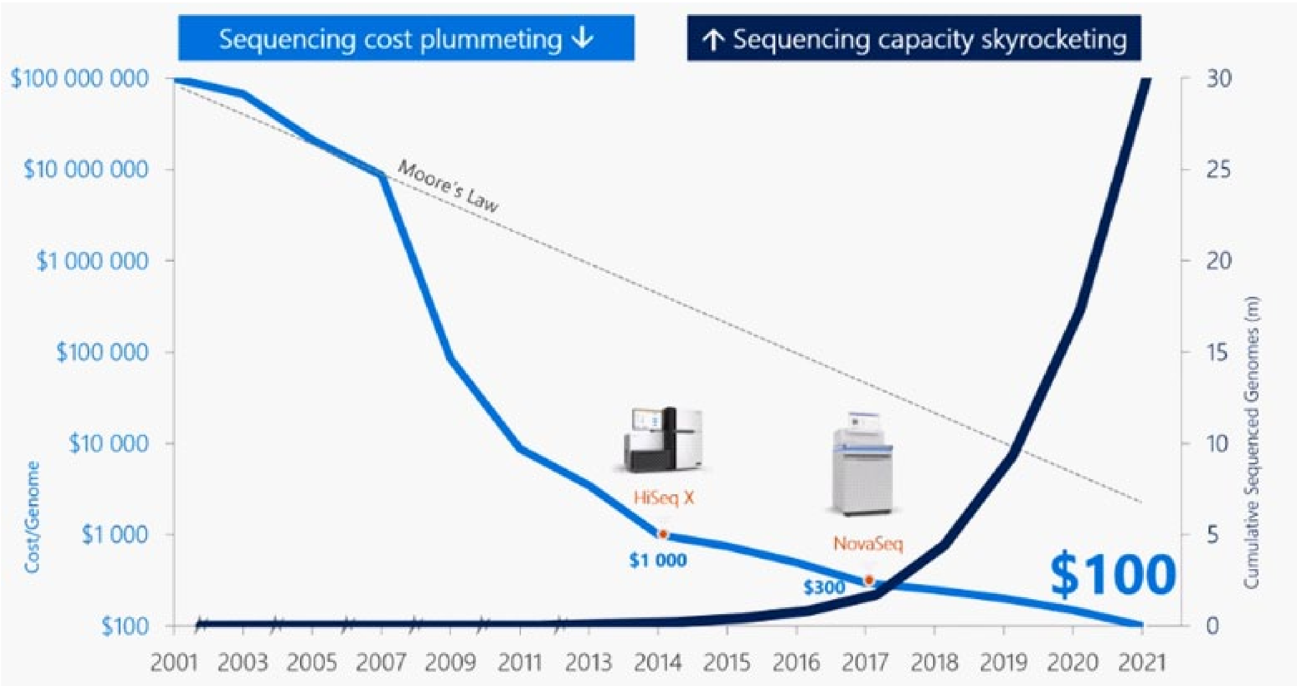
## LOOKING FOR A NEEDLE IN A HAYSTACK

Population-level genome sequencing will be necessary to decipher the hidden "fingerprint" of a disease in DNA, predict the possible disease progression and the organism's response to treatment, and develop clinical decision support models. The result will not only be the ability to treat diseases against which we are helpless today, but also the explosion of genetic data and the increase in the computing power required to analyze these data (tens of exabytes and trillions of hours of work in the next five years[2]). If looking for an effective therapy is the proverbial search for a needle in a haystack (of data), then processing these massive amounts of data will require agility, easier management, security, and access to storage space and computing power. All of this must be economically possible.

To support doctors' efforts and accelerate progress, the medical and scientific community is building databases such as the St. Jude Cloud, the American CDC Nhanes[3] or the British Biobank[4]. Microsoft Genomics, on the other hand, makes its solutions – enabling highly sophisticated analyses – available to the general public in line with the *open source* approach on GitHub[5]. Managing the work and workflow related to DNA sequencing is possible thanks to the Cromwell platform, a solution that is well known in the world of science. And since it is available on the Azure platform, it can be used in practice in a very convenient way. Jupyter Notebooks and Genomics Notebooks are ready--to-use scenarios for DNA variant and variation detection, filtering, annotation, and transformation of genotypic, phenotypic, and clinical data into multimodal data sets (frames) used to build machine learning models. The rich set of tools that allow researchers to focus on verifying research hypotheses is supported by a suite of Bioconductor technologies, pre-developed as ready-to-use virtual machines.

According to research by DNAnexus, Microsoft's partner, the number of genome sequencing operations is growing even faster than the computing power of computers (as shown in the graph above). The authors of the study predict that 30 million genomes will be sequenced worldwide by the end of 2021. This will translate into more than 700 petabytes of data and 1.3 billion computing hours.

The Microsoft Genomics initiative is making the necessary tools and computing power available on a scale unheard of before – genetic research and combining it with phenotypic data is becoming increasingly democratic. Polish



scientists and experts specializing in various fields of medicine are thus free to make use of the latest achievements in genetics and conduct advanced research for the benefit of Polish patients and the "great human family" inhabiting the world.

But will Polish medical professionals manage to gain access to high-quality data of Polish patients legally, safely, and with a guarantee of confidentiality and anonymity?

**TOMASZ JAWORSKI**
*(The author's profile is included in Chapter I.)*

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Example of application

# Robots, diseases and mosquitoes – solutions to 10x problems[1]

Tomasz Jaworski

## → The Microsoft Premonition project aims to provide scalable environmental monitoring for early detection of disease threats with the utilization of robotics and genomics

Mosquitoes are "flying syringes". They suck the blood of their hosts on a mass scale over vast areas – together with the pathogens it contains, i.e. viruses and bacteria. If mosquitoes could tell us where they picked certain germs from, we could create an interesting hazard map and perhaps learn early about a disease spreading in a given area. Wait a minute... mosquitoes can, in fact, give us information! Just how do we get it from them?

### OUR HEALTH DEPENDS ON UP-TO-DATE PATHOGEN DATA

Epidemics have affected every society and economy in human history. The key to reducing future outbreaks is early detection of potential pathogens before they turn into large epicenters. This lets researchers gain time to develop new treatment methods, public health organizations – time to prepare responses, and individuals – time to minimize the risk of getting sick.

However, detecting pathogens before they cause epidemics is not an easy task. Pathogens 'travel' through the environment in complex ways that are difficult to monitor using traditional methods. It is estimated that 60-75% of emerging infectious diseases are caused by pathogens transmitted from animals to humans. Zika virus, dengue virus, and West Nile virus move between humans, animals, and mosquitoes in complex cycles. Fortunately, we already have limited technologies and capabilities to monitor potential pathogens moving through the environment.

Microsoft Premonition aims to provide scalable environmental monitoring for early detection of disease threats with the utilization of robotics and genomics. Robotic smart traps continuously monitor the environment for important types of insects, such as mosquitoes, which both transmit pathogens and collect blood samples from other animals. Meanwhile, cloud-scale genomic analyses try to identify all the species of organisms and viruses in environmental samples to spot new transmission patterns.

### ROBOTS CATCHING MOSQUITOES

Arthropods (e.g. insects, arachnids, crustaceans) are animals with the largest number of species in the world. They are essential to our ecosystems (as crop pollinators, food for larger animals, predators of smaller arthropods, and natural recyclers). However, arthropods such as mosquitoes are some of the most important transmitters of pathogens that cause human diseases. Monitoring mosquito populations and predicting their distributions is essential for predicting future disease outbreaks.

**→ Microsoft Premonition's robotic smart traps are designed to adaptively lure, identify, and selectively capture targeted mosquito species in the environment.**

We believe that robotics has the potential to dramatically scale the monitoring of these major disease carriers. Because there are thousands of known mosquito species, we are exploring state-of-the-art AI-based species identification, developing novel robotic designs, and building unique capabilities to evaluate designs on many mosquito species.

## WORKING WITH PARTNERS

Developing scalable monitoring solutions for the rich world and nature that we live in is an interdisciplinary effort requiring efforts to be made by a diverse set of partners. Microsoft Premonition's team embraces academic, governmental, and industrial partners to help deploy and evaluate our technologies in complex ecosystems. We have focused our field deployments on answering several related scientific questions:

1) How many types of arthropods will visit a robot, and how hard is it to autonomously classify them?;
2) Can autonomously collected data be used to build better forecasts of disease risks, and can those forecasts be used to better inform human health programs?;
3) How reliably can microbes, viruses, and other environmental DNA be recovered from robotically collected specimens in urban and rural environments?

Working with Harris County Public Health (a local health department in the U.S. county of Harris), Microsoft Premonition tested its technologies in Houston, TX during the peak of Zika transmission risk in 2016. The trial proved that robot field biologists could be trained to identify and selectively capture medically relevant mosquitoes with high accuracy (> 90%). Microsoft Premonition's robots were also able to digitize mosquito behaviors at high resolution, which translated into a better understanding of how they moved through the environment. The genomics analyses carried out as part of the project made it possible to detect microorganisms and viruses in mosquito specimens, and identify the types of animals on which they fed. Since then, Microsoft Premonition has explored diverse habitats – ranging from the southern tip of Florida to the remote forests of Tanzania. Along the way, the research team has continued to learn how these technologies and data sets can assist project partners with their essential human health missions.

## DETECTING POTENTIAL PATHOGENS WITH DNA SEQUENCING

Monitoring the environment for pathogens is difficult because detecting microorganisms and viruses usually requires targeted chemical tests (or arrays of chemical tests). It may be unclear which tests to run on a sample. Also, targeted tests may not exist for a given case. Fortunately, DNA sequencing opens the door to new broad-spectrum approaches. By converting the genetic material of an environmental sample into digital data, we can computationally scan a sample using trillions of genetic signatures to discern the viruses, bacteria, fungi, and higher-order life in a sample.

Microsoft Premonition metagenomics[2] pipeline estimates the organisms and viruses in a sequenced environmental sample using cloud-scale machine learning and a large database of reference genomes spanning the tree of life. This technique allows us to test for all known sequenced pathogens and also detect related viruses and bacteria. Because we also scan for higher-order life, we can look for complex associations between potential pathogens and their possible hosts. For instance: does an unknown virus tend to appear in mosquitoes that have evidence of feeding on both birds and humans? Let's imagine a situation where e.g. a trace of DNA from such a virus appears in mosquito metagenome samples that simultaneously have traces of DNA proving that both birds and humans were their hosts. This will be a signal that the virus from the bird body has spread to humans through mosquitoes. It will be then possible to further investigate the possible harmfulness of such a virus for humans and to take effective preventive measures in advance using the medical methods available today.

**TOMASZ JAWORSKI**

*(The author's profile is included in Chapter I.)*

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1. The idea of solving so-called "10x problems" is about distancing yourself from your current way of thinking about problem solving and approaching the solution by setting it on a scale an order of magnitude larger. For example, instead of testing individuals for a single pathogen, let's think of a way how to test all people for all pathogens. The point is not to look for a solution that is more complicated than what is actually needed, but to simply explore solutions from a 10X perspective. This approach is proposed, discussed, and supported by examples in the book "The TenX Rule" by Cardone Grant.
2. The term 'metagenome' was first used by Jo Handelsman (Handelsman, J.; Rondon, M. R.; Brady, S. F.; Clardy, J.; Goodman, R. M. (1998), *Molecular biological access to the chemistry of unknown soil microbes: A new frontier for natural products*, Chemistry & Biology 5 (10): R245.) A metagenome is a pool of DNA of organisms inhabiting a particular environment (e.g. a metagenome retrieved from a soil sample).

# Chapter IV.

# Strategic directions of development of artificial intelligence in the healthcare sector in the European Union

ROMAN BIEDA,
MIROSŁAW WRÓBLEWSKI

- **The European Union has prepared a comprehensive regulatory and program package with plans of a number of actions for AI mechanisms in the health sector**
- **It is to be expected that the right concepts concerning healthcare as set in the Polish strategy for AI are turned into concrete actions for the benefit of the patient and the whole sector**

## ARTIFICIAL INTELLIGENCE FOR EUROPE

In April 2018, the European Commission published a communication titled "Artificial Intelligence for Europe"[1]. The document discusses the opportunities and challenges for the development of AI in the European Union, putting particular emphasis on AI research and development, the creation of research networks and centers of excellence, and funding investment projects and innovation to further AI – including in the area of Member States' healthcare systems. Stressing the crucial importance of ensuring the quality and quantity of data for AI to work effectively, the Commission announced a number of actions – involving both regulatory measures and investments – to expand the European data space. When it comes to artificial intelligence in the health sector, the European data strategy with its draft act on data management deserves special attention.

## COORDINATED PLAN AND WHITE PAPER ON ARTIFICIAL INTELLIGENCE

When implementing the artificial intelligence strategy adopted in April 2018, in December 2018, the Commission presented a coordinated plan designed jointly by EU Member States with the aim to support the development and use of artificial intelligence in Europe[2]. It proposed some 70 joint actions for closer and more effective collaboration between Member States and the Commission in crucial areas for AI.

In its strategic document titled "White Paper on Artificial Intelligence", adopted on 19 February 2020, the European Commission identified the main priorities the European Union was to focus its efforts on. The six strategic actions included e.g. the creation of AI research and excellence centers and networks of leading universities under the Digital Europe Programme, the establishment of one or more national digital innovation hubs, and the promotion of public-private partnerships in AI, data, and robotics. While virtually each one of these activities contributes to the development of AI in the health sector, activity #6 emphasizes making healthcare a priority. What is important to notice here is that the "White Paper" stresses the need to create a new legal framework for the functioning of AI in the European Union or to update the existing legal regulations which are already in place.

## EUROPEAN STRATEGY FOR DATA

Artificial intelligence has no chance to develop without processing huge amounts of data (*Big Data*). When it comes to the domain of healthcare, it is important to use health data on a large scale to make progress in disease prevention, diagnosis, and treatment. Therefore, aware of the existing barriers to accessing and sharing data, the European Commission announced a "European strategy for data" on 19 February 2020[3]. The Commission argued that the EU would only be able to make full use of the potential of digital innovation if researchers and businesses had access to data. This issue is particularly relevant for the construction of AI mechanisms applicable to healthcare, where the particularism of national solutions prevents patients from e.g. having access to their medical data (medical records) in any Member State, and thus limits, for example, the potential of artificial intelligence. In the European strategy for data, the Commission announced the creation of a Common European health data space as one of the nine priorities. This is because the EC recognized that such space was necessary to make real progress in disease prevention, detection, and treatment – and to make informed, evidence-based decisions to improve the accessibility, effectiveness, and sustainability of healthcare systems. To this end, the Commission committed itself to develop legislative and other measures for the Common European health data space and to deploy data infrastructures, tools, and computing capacity for this space. It was also considered necessary to scale up the cross-border exchange of health data within the EU and to link and use – through secure, federated repositories – specific kinds of health information, such as electronic health records, genomic information, and digital health images.

The Commission plans to enable the exchange of electronic patient summaries and ePrescriptions between the 22 Member States participating in the eHealth Digital Service Infrastructure (eHDSI) by 2022 and start cross-border electronic exchanges through eHDSI of laboratory results, discharge reports, and medical images, whose database has been consistently extended since 2020 with the support of the Horizon program (especially the base of images for cancer detection and treatment).

The European Commission will also support big data projects. These actions will support prevention, diagnosis, and treatment (in particular in the case of cancer, rare diseases, and common and complex diseases), research and innovation, policy-making, and regulatory activities of Member States in the area of public health. Given the impressive diagnostic results in terms of, for example, skin cancer detection[4], the progress in this field could revolutionize at least some areas of medicine.

## DATA GOVERNANCE ACT

On 25 November 2020, the European Commission presented a draft version of its Data Governance Act[5] as part of the implementation of the European strategy for data. In this legislative proposal, the Commission stressed that a single market for data should ensure that data from the public sector, businesses, and citizens can be accessed and used as effectively and responsibly as possible, while businesses and citizens keep control of the data they generate and the investments made into their collection are safeguarded. At the same time, the draft act emphasizes the need to respect fundamental rights, including in particular the right to privacy and the protection of personal data, in pursuing these objectives. Such an assurance is particularly necessary as far as medical data (health data) are concerned. Indeed, with regard to the processing of personal data by AI mechanisms, various doubts are brought to light, e.g. concerning the compliance with the principles of minimization or purpose limitation as defined in the GDPR[6]. The draft act specifies the use of data made available voluntarily by data subjects based on their consent or, where it concerns non-personal data, made available by legal persons, for purposes of general interest. Such purposes include especially support to scientific research including e.g. technological development, fundamental research, applied research, and privately funded research. In this context, the regulation aims at contributing to the emergence of pools of data made available on the basis of data altruism that have a sufficient size in order to enable data analytics and machine learning, including across borders in the European Union.

## ARTIFICIAL INTELLIGENCE ACT

In April 2021, the European Commission presented a draft version of the Artificial Intelligence Act[7]. It was a sign that the European Union moved from the phase of planning of activities to be undertaken in relation to artificial intelligence to the stage of legal regulation, showing that it prioritized and took this rapidly growing sector of activity seriously. One of the most important areas of this activity is the healthcare sector, where the use of AI is considered as having great potential both for the entire healthcare system and, above all, for the patients themselves (e.g. in diagnostics or personalized medicine, or in fighting epidemics). At the same time, it needs to be emphasized that the legislator perceives artificial intelligence in the area of healthcare as a great opportunity to improve the effectiveness of medicine (e.g. in rapid combating epidemics[8]) but also recognizes the risks that its use may involve and cause (high-risk AI[9]). For this reason, it seems necessary for regulatory efforts to take place at EU level, especially given the rapidly growing number of applications and impacts of AI in the medical sector[10]. Indeed, it is necessary to build trust in artificial intelligence at various levels[11].

## HEALTHCARE SECTOR IN THE AI STRATEGY FOR POLAND

In January 2021, the Polish Council of Ministers adopted the "Policy for the development of artificial intelligence in Poland from 2020"[12], sometimes referred to as the "AI strategy". In general terms, the document describes the goals and activities that should be implemented in order to develop Polish society, economy, and science in the field of artificial intelligence. The following areas are distinguished in the AI policy:

- AI and society,
- AI and innovative companies,
- AI and science,
- AI and education,
- AI and international cooperation,
- AI and the public sector.

Each of these areas covers a set of objectives and a range of tools designed to make it possible to pursue and achieve these objectives, divided into short-term, medium-term, and long-term perspectives. Also, strategic partners were identified for each of the areas to ensure the achievement of the set objectives.

Like in the case of the documents adopted at the EU level, the AI policy for Poland draws attention to the importance of using artificial intelligence in the medical sector. It has actually been listed among the priority sectors in which the development and implementation of artificial intelligence will bring the greatest benefits to the entire Polish economy[13]. It is emphasized that the use of artificial intelligence can contribute to the provision of high-quality medical services, optimizing the time, cost, and effectiveness of treatment[14]. The potential of using artificial intelligence to predict the development of epidemics and detect fraud is also highlighted[15].

Given the role of data in the development of artificial intelligence, the AI policy pays special attention to various aspects of providing access to and sharing data. In this respect, one of the tools to eliminate legislative barriers for new entrepreneurs dealing with AI is to involve an update to "the law on ensuring access to data, including sensitive data (e.g. medical data), and the conditions for trusted spaces for sharing such data, taking into account privacy and personal data protection"[16].

In the area of AI and the public sector, one of the short-term objectives (i.e. set to be achieved by 2023) is to "harness the research potential of health data to improve citizens' health, taking into account the protection of privacy and personal data, with the use of privacy protection techniques (e.g. anonymization or pseudonymization) or without the use thereof where the consent of the right holder is explicitly given"[17]. The above objective is to be achieved using such tools as:

- pilot programs for storing anonymized medical data;
- support for the development of tools and solutions using medical data – including in particular telemedicine and e-health solutions;
- analysis of data on medical events (medical services), which can contribute to the effectiveness of preventive actions;
- optimization activities in the health sector, taken based on analysis of data such as e.g. needs maps, supply and demand for services, resource utilization, data from digital services;
- sharing of medical data for the development of more effective medicines and treatment methods[18].

A number of other goals and tools described in the various areas of AI utilization apply also to the medical sector and will affect the development or use of artificial intelligence in medicine and healthcare understood in broad terms. For instance, let us consider the measures proposed to ensure the development and use of AI in an ethical manner, to ensure security and build public trust in AI solutions, to facilitate and encourage companies developing AI systems, or to develop education in the field of AI.

The AI policy emphasizes that for the Polish society and economy to seize the opportunities offered by artificial intelligence, it is necessary to coordinate the activities of all actors of the Polish AI ecosystem[19]. At the same time, it is stressed that it is necessary to engage collectively in e.g. supporting e-health projects, especially those related to elderly care, counteracting epidemics – and fighting their effects[20].

It should be emphasized that the AI policy is intended to be a 'live' document that will be reviewed and adapted to changes in the new technology sector, particularly in the light of the ongoing development of artificial intelligence. It would be advisable to adopt also a separate, detailed strategy on the use of artificial intelligence in the health sector.

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# Ethical challenges of AI in the health sector

ROBERT SROKA

- **Bioethics was a response to the technological progress, which came ahead of legal regulations and often violated ethical norms, but opened the door to better solutions that saved life and health**
- **AI in the health sector holds great promise but also faces ethical challenges which call for a combination of expertise in AI ethics, medical ethics, and bioethics in order to be solved**

We can already see artificial intelligence systems play an increasingly important role in the health sector, in terms of system-wide operations, medical facility management, and patient treatment alike. AI can surely bring a range of benefits to the health sector, but whether it becomes socially acceptable will depend on both its technical effectiveness and 'ethicality'. This is why the issue of the ethics of artificial intelligence systems in the health sector is so important. At the same time, it is extremely challenging. First, because it directly affects the fundamental values of human life and health. Second, it requires an interdisciplinary combination of at least three ethical areas – artificial intelligence ethics, medical ethics, and bioethics. The latter seems to be particularly relevant here, not only because of the object of research, but mainly because of the method of reconciling ethical positions worked out over the last decades. In many cases, due to the very nature of artificial intelligence, it is reasonable to make use of procedures utilized in bioethics to evaluate the ethicality of AI.

A short article does not offer enough room to discuss in detail the enormity of the ethical challenges underlying the use of AI systems in the health sector. Therefore, I will only briefly mention some selected aspects that are important and worth further analysis. I will start from discussing the main ethical issues concerning AI and the most important documents prepared by international and national institutions that set the framework for the ethics of artificial intelligence. Then, I will indicate the key areas of medical ethics and bioethics that should be borne in mind when dealing with ethical dilemmas related to the use of AI in the health sector.

## SELECTED ETHICAL CHALLENGES

The intensified development of AI research over the past decade or so has resulted in solutions that are already significantly affecting what we think and how we build social relationships. In many cases, it is an influence that we are not aware of, if only in terms of making purchasing decisions, i.e. mainly in business, but also in education, science, culture, and means of communication – with particular emphasis on social media. This influence is often so strong that it touches upon the core ethical values of human rights founded on the category of dignity. To better understand the ethical challenges of AI in the health sector, it is reasonable to look at the most important ethical issues related to the utilization of AI systems in general.

One of the most widely used methods in AI systems considered in broad terms is machine learning. Its variation, supervised machine learning, which involves refining statistical models based on large data sets, includes tasks and solutions to those tasks. Based on training data, a statistical model "learns" the relationships between tasks and solutions. These techniques, particularly linear regressions, have long been used in medicine. A certain novelty in machine learning is the use of neural networks, which make it possible to e.g. create new solutions based on existing data. The problem is that in order to train a neural network, you need a large number of examples with a large variety that would make it possible to detect the existing dependencies. If this condition is not met, erroneous results are produced. AI systems therefore depend on the quality of the input data. Their reliability, in turn, depends on whether we know on what basis the trained models that use new data make decisions. If a model has learned to recognize erroneous relationships using training data, it will make errors that can lead to exposing patients to various risks in medicine when using new data. An example of such discriminatory error was an AI system used in U.S. hospitals. It was to qualify patients for specialized treatment programs, taking into account the annual cost of treating an individual. In deciding to make use of this data set, the system's designers failed to consider the fact that in the United States, the spending on the treatment of black people is statistically lower than in the case of white people suffering equally from the same disease. In consequence, the system replicated the pattern resulting from the existing economic inequality by classifying black people as "less sick" than they actually were[1]. Thus, the very quality of the data and the reliability of the results are ethical categories. It also turns out that trained models are often wrong in their assessment of real cases. Therefore, the accuracy of the decisions made is another ethical category – not just a praxeological or economic one. To summarize this one of the most important issues in AI ethics, I will use the following analogy: just as the brain needs oxygen, artificial intelligence needs data. If the air mixture is poisoned or inappropriate, it poisons the brain or causes delusions leading to a distorted perception of the surrounding world. The same is true for AI systems: poor quality data distorts the results of artificial intelligence systems. When such system are widely used in the health sector, this can lead to negative effects on a large scale.

Another broad spectrum of ethical challenges occurring particularly in the health sector is the matter of data acquisition and the related issues of privacy, data security, and how data are used.

## CODES OF ETHICS FOR AI SYSTEMS

Due to the rapid development, the profound impact on many different areas of life, and the wide reach of artificial intelligence systems, individual countries and international organizations have committed themselves to develop ethical principles for AI.

→ **It is important to notice that a race of sorts is underway to impose an ethical narrative for artificial intelligence. This is done by countries such as: Canada, France, Australia, the UK, Japan, China, but also India. International organizations are also involved. The efforts made in this respect by the OECD, UNESCO, and the European Union deserve particular attention.**

In 2019, the Organisation for Economic Co-operation and Development (OECD) published the first intergovernmental standards for the development of artificial intelligence – *"Recommendation of the Council on Artificial Intelligence"*. In the paper, the OECD stresses that artificial intelligence should benefit people and the planet by driving inclusive growth, sustainable development, and well-being. The OECD notes that AI systems should be designed to take into account the rule of law, human rights, democratic values, and diversity. They should also include adequate safeguards to allow human intervention where necessary to ensure a just society. The paper also addresses the issue of accountability by indicating, in line with the above principles, that organizations and individuals developing, implementing, or operating artificial intelligence systems should be held accountable for the proper functioning of such systems.

UNESCO's work on AI ethics has a global impact too. The ethical proposal of this organization is based on values such as the dignity of each person, human rights, and fundamental freedoms. Its document emphasizes the basic principle of no harm – be it physical, economic, social, political, or psychological harm – in any phase of the "life cycle" of artificial intelligence. When discussing the application of AI in the health sector, it seems to be reasonable to mention that in promoting and developing the ethical principles for AI, UNESCO works closely with the International Bioethics Committee and the Intergovernmental Bioethics Committee.

Another important initiative addressing AI ethics is the Ethics Guidelines for Trustworthy AI, published by the European Commission and prepared by the High-Level Expert Group on Artificial Intelligence. The authors of the document were primarily guided by an approach in which the human being stands in the center of ethical reflection (*Human-Centric AI*). According to this proposition, artificial intelligence should first and foremost be lawful, ethical (meaning consistent with ethical principles and values), and robust (meaning reliable, socially and technically 'durable').

Meanwhile, in April 2021, a Proposal for a Regulation of the European Parliament and of the Council laying down harmonized rules on artificial intelligence was presented. The document is the result of legislative work aimed at maintaining the EU's technological leadership while ensuring that Europeans can benefit from new technologies developed and operated in accordance with the European values, fundamental rights, and essential principles. The purpose of this act is to propose an ecosystem for building trustworthy artificial intelligence. An important thing is that enhancing human well-being has been identified as the ultimate goal for artificial intelligence. The main ethical framework for AI has been set: safety, legal compliance, and compliance with respect for fundamental rights and EU values. Among the set of fundamental rights, emphasis is put on ensuring human dignity, respect for private life, and protection of personal data, non-discrimination, and equality between men and women. These regulations aim also to prevent a chilling effect on the rights to freedom of expression and freedom of assembly. Therefore, a ban on some particularly harmful practices using AI that go against EU values has been proposed. A methodology for evaluating artificial intelligence systems is also in place to identify those that involve high risk and pose a significant threat to human health and safety or fundamental rights. Special evaluation and surveillance procedures have been provided for this category of AI systems.

At the end of 2020, Poland adopted its own policy for the development of artificial intelligence, which repeatedly stresses the importance of ethics. The document makes it clear that it is crucial for the AI solutions created to always serve the human being, putting human dignity and rights first. It also emphasizes Poland's ambition to be an active participant in the global debate on the ethics of artificial intelligence.

## AI ETHICS IN THE HEALTH SECTOR

The ethical reflection on the application of artificial intelligence systems in the medical sector cannot be limited to the current state of knowledge on the ethics of AI. It should take into account the perspective of medical ethics and bioethics. Developers of artificial intelligence systems for the health sector should take into account the considerations that shape the ethical framework of the physician's standard practice, which include principles such as patient welfare, patient autonomy, and social justice. The principle of utmost priority of patient welfare must not be overridden by business considerations, administrative requirements, or the use of unproven or non-transparent technologies. Also, the principle of patient autonomy, i.e. the possibility to make conscious decisions regarding treatment, may be disturbed by new technologies in medicine, based on artificial intelligence systems whose creators did not foresee the possibility of materialization of the principle of patient autonomy at the stage of development. The third important principle in medical ethics is the principle of social justice, which refers to the fair distribution of resources and the elimination of discrimination in health care. As shown by the many examples of artificial intelligence systems already analyzed, the problem of AI algorithm bias (*algorithmic bias*) is one of the most serious challenges to face, which may lead to dangerous cases of discrimination. Another important challenge is the problem of observing professional secrecy, which, with artificial intelligence systems that "thrive" on data, is certainly a big issue.

AI is yet another important development in the technology that has spawned a new field of applied ethics. This field is bioethics, understood as formulating judgments and norms concerning biomedical interventions connected with the beginning of human life, its duration, and death[2]. The interest in bioethics stems from the need to reflect on life and death in the conditions of modern technical civilization, as well as the need to adopt rules that enable us to make decisions in extreme and disputable situations. The discussions and disputes revolving around bioethics address the problem of the relationship between the progress of civilization and morality. So far, the advances in science and technology have made it ahead the existing legal norms and violated moral standards. In the past, however, the disparity between practice and moral principles did not have the far-reaching consequences that we can see today. Applying the existing technical capabilities beyond ethical control raises new problems that once did not exist and that need to be resolved – especially in the field of medicine[3]. This is why the subject matter of ethics of artificial intelligence systems is so important and, in my opinion, should draw on the methodological achievements of bioethics. Moreover, when it comes to medical grounds, the ethics of artificial intelligence will have to face a major bioethical dispute that is still ongoing – and where the two main contenders are the value of life and the quality of life.

When thinking about the development of AI ethics in the health sector, there are several elements that should be kept in mind:

- AI systems will be as ethical as their creators are. Therefore, when it comes to the domain of ethics of artificial intelligence systems in the health sector, there should be a special focus on the developers of these systems.
- Anticipating consequences and reacting quickly are highly important aspects of AI ethics. We need new institutional mechanisms for ethical evaluation of AI systems, which should be: interdisciplinary, responsive, systematic, and causative. In the case of the health sector, it is reasonable to drawn on the experience of bioethics committees whose main objective is to protect human dignity.

- As for AI ethics, we should be especially mindful of the difference between merely feeling that something is ethical and whether it actually is.
- In the domain of AI, like in the sphere of medicine, prevention is better than cure, which is why it will be so important to make sure that the new forms of AI are trained in so-called *sandboxes*, i.e. tested in isolation, before being applied in practice in the health sector.

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# Legal challenges of AI in the health sector

ANETA SIERADZKA

- **Legislative work on artificial intelligence in medicine is necessary to integrate AI into the healthcare system**
- **Barriers need to be removed from the regulatory framework. It is also important to determine the extent of responsibility of the doctor, the patient, the technical service, and the medical facility**

New technologies make the world change before our eyes. They make our work easier, bring relationships online, and at the same time process massive amounts of data, including health data – an estimated 30% of the data stored globally is health-related. The common use of solutions based on artificial intelligence around the world is becoming a standard, although it is still beyond the reach of most medical facilities in Poland. Here, the potential of AI to improve the healthcare system, facilitate access to better healthcare services, and support the work of doctors and administrative staff of medical centers is not made use of. Analyzing massive data sets requires a shift in thinking in the medical community and, most importantly, the emergence of the right regulatory framework – able to keep up with the evolution of technology in medicine. Because the key is to make sure that AI complies with the law.

## CURRENT OPPORTUNITIES TO APPLY AI IN MEDICINE

The development of medicine is unstoppable. This means that legal standards should follow the needs of medicine – especially in the area of new technologies. The number of domains where AI is applied and where the process of delivering benefits becomes easier, more accessible, and faster is growing year by year. Artificial intelligence can streamline processes at several levels in a medical facility, from HR or legal departments to AI-based patient appointments – it will serve the patient at the reception desk, reminding them also about their appointments or the need to prepare for an appointment or test. Patients may contact a medical facility first through AI. It's not necessary to contact a human being to make a medical appointment successfully or to find out that there's no need for an appointment. Statistics show that only one out of every three visits to a primary care physician is actually justified on the grounds of health problems. This means that there is a need for solutions that would qualify the patient's needs at this stage. AI shines the brightest in diagnosis and prevention, which is of considerable importance for an aging population, extended life expectancy, and – therefore – a longer demand for health services and an increasing number of geriatric patients.

Digitization and analysis of health data offer tangible benefits to the system and citizens. Among the many possibilities of using AI in the health sector, there are such areas of medicine as personalized medicine (matching drugs to patients according to their genetic profile), transplantology (typing patients for transplants at dialysis centers, matching donors with recipients, delegating administrative tasks of transplant coordinator to artificial intelligence), oncology (disease prediction), genetics, cardiology, dietetics (selection of a diet according to the disease), as well as the area of clinical trials and drug testing, data management, and defining patients' needs both before and after procedures – also in the area of aesthetic medicine and *beauty*.

The outbreak of the COVID-19 pandemic on an unprecedented scale has triggered a demand for diagnostic tools in the form of tests for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The coronavirus pandemic has forced not only policy makers but also medical facilities to look for effective and efficient solutions. For instance, the Damo Academy research institute, owned by Chinese *e-commerce* tycoon Alibaba, has developed an artificial intelligence algorithm that can detect coronavirus infection with up to 96% accuracy. The algorithm analyzed the data of five thousand people with positive test results, and the whole process took just 20 seconds. Making effective use of the new tool enables doctors to diagnose patients even faster. The algorithm was first applied at the newly built Qiboshan Hospital in Zhengzhou, Henan Province.

## PROSPECTS FOR AI DEVELOPMENT IN THE COMING YEARS

The Polish healthcare system, struggling with numerous organizational, financial, management and legal problems, is a fertile ground for the development of new technologies in medicine. This is because AI supports and improves the processes that humans tend to fail at. Artificial intelligence in the Polish health sector has great potential to become an integral part of the healthcare system. In order for AI to develop, it is extremely important for policy makers and legislators as well as the medical professionals and patients who will benefit from digital solutions to be aware of it and its role in the first place.

When setting the directions of development and listing the benefits that are mutual for all actors of the healthcare system, it is also important to anticipate the risks and threats that AI brings. Defining the potential risk areas in detail will translate into tangible benefits that AI solutions can offer. That is why it is so important for digitalization to take into account digitally excluded patients (due to age, social status, education, access to the internet) and for dedicated legal solutions to guarantee equality for patients – instead of discrimination.

Creating a consistent concept for the next few years for the development of AI in the healthcare system calls for 'redesigning' many of the existing legal solutions. There are solutions created in Poland that are supposed to make it easier for patients to make use of medical services, but the ideas are sometimes turned into reality thoughtlessly, without taking into account the reality of lives of millions of Poles. Being aware of the needs and capabilities of patients is important to be able to design effective and socially useful solutions.

An important thing to notice is the lack of a definition of legal medical documentation, which in practice poses problems for both doctors and patients. Another issue to consider is the elimination of such problems as difficulties involved in the verification of the identity of the patient, their legal representative (especially when the parent has a different surname than the child), or the restriction of access to the patient's medical records by their life partner, which creates unnecessary obstacles in the light of absence of a proper law regulating the matter of domestic partnership. Legal solutions are to serve medical professionals and patients, not to act as unnecessary barriers. There are many such barriers in the legal system, and they need to be eliminated.

It is certainly necessary to create a nationwide strategy for the development of AI for the health sector, which will provide a reliable lodestar for the designed and implemented changes. They need to be coherent and consistent, not chaotic. One of the areas of the strategy should be an audit of the laws regulating the provision of health services, conducted with the aim to identify changes in individual laws and regulations so that they do not contradict each other. Moving forward – identifying new solutions and legal institutions that would be subject to standardization, especially in the area of accountability in connection with the use of AI from several perspectives: the medical facility, the doctor, the AI technician, but also the patient. Where new technologies and patient health and life meet, it is impossible not to hold the patient co-responsible for their safety.

The establishment of expert advisory bodies at central authorities (Ministry of Health, Patient's Ombudsman) for AI in the health sector is another important step in laying a solid foundation for efficient implementation of artificial intelligence. The Polish healthcare sector has already reached a milestone in its approach to privacy, including the protection of medical data, the safeguards used, but also the greater awareness among medical professionals and patients themselves in connection with the entry into force of the EU General Data Protection Regulation[1]. It's a process because medical data security means new challenges posed by new technologies[4]. The ongoing trend of implementing digital solutions, including EMR[2], OPA[3], as well as a number of e-health tools such as e-prescriptions or e-referrals, and the accelerated development of telemedicine during the pandemic period – all this reinforces the belief that both the medical community and the patients themselves take advantage of the benefits of new technologies in the domain of health more often and more willingly.

This social and market potential calls for analyses and compatibility of the proposed changes to synchronize artificial intelligence with numerous legal norms, ranging from fundamental human rights to international, EU, and national regulations. It requires solutions that are consistent with the Constitution of the Republic of Poland (the principles of the rule of law, social justice, freedom of rights and human beings, the principle of subsidiarity) and sectoral regulations – laws aimed at individual medical professions and regulations governing the activity of e.g. medical facilities, pharmaceutical companies, pharmacies, manufacturers of medical devices, and other entities involved in the process of providing health services.

Access to confidential medical data is of great importance in the application of AI, which in the face of the development of AI would require strengthening the institution of medical confidentiality for the sake of the safety of the doctor and the patient alike[5].

Another area that needs to be addressed is the current lack of sufficient regulation of genetic testing. This is a matter of great importance, because DNA sequencing indicates, for example, the risk of contracting certain diseases, which is of great significance for prevention and for defining population diseases with the help of AI. Medical laws in Poland are gradually being adapted to the needs of medicine. Setting new directions by developing strategies and creating hybrid bodies of AI experts in the health sector will make it possible to create effective and safe solutions that will strengthen and facilitate the process of providing health services.

## AI VERSUS THE HUMAN FACTOR AND THE REMEDY FOR STAFF SHORTAGES

The human factor is unreliable and prone to making mistakes. In medicine, fatigue and routine are the most common causes of human error. These mistakes are caused by exhaustion, emotions, lack of concentration, forgetfulness or dissatisfaction with working conditions and pay. Artificial intelligence is clarity, transparency of processes, and elimination of irregularities typical of a human being. AI means elimination of unethical human behavior, but also of possible corrupt activities in access to health services – particularly highly specialized ones, which involve long waiting times for consultations or procedures.

AI is the remedy for medical staff shortages because it is easier to create good algorithms than to spawn thousands of medical professionals required to fill the gaps. Of course, AI will not eliminate the doctor from the treatment process, but it can perform many time-consuming tasks for them. AI increases patients' chances for better quality medical services – faster, transparent, user-friendly. Above all, artificial intelligence is an opportunity for the health care system, which can be cured by algorithms. Yes, algorithms are devoid of empathy, but humans don't show empathy in every situation either.

## MEDICAL ERRORS AND ACCOUNTABILITY

Accountability for medical errors made when using AI is a particularly important issue. There would need to be new, detailed accountability rules for mistakes committed by artificial intelligence. It is impossible to imagine that the responsibility for an error made by an algorithm would be borne by a physician on the same basis as it is borne by a physician today, i.e. under professional liability. The responsibility for AI errors should lie with the medical facility that provides health services (this is especially important in the context of international telemedicine, medical data transfers outside the EU, and diagnostic errors) using artificial intelligence. This should include civil liability as well as administrative or even licensing sanctions – if the use of AI in the area in question requires a license. It is therefore necessary to draw lines of responsibility between the doctor, the medical facility, and the employee operating the ICT systems. In the case of the latter, given the large scope of liability, the general principles of liability today may not be appropriate to the extent of the potential damage. Therefore, the liability rules for IT employees would need to be detailed. Also, an obligation to have third-party insurance should be adopted.

When formulating the principles of AI accountability, it is impossible to ignore the responsibility of the patient, who has been given a full range of rights by the system. It is therefore necessary to burden the patient with the obligation to know the rules under which the service is provided when using AI (the matter of notification duty and informed consent extended to AI). It is also important to hold the patient accountable for blatant non-compliance, such as failing to inform of canceling an appointment. With traditional visits, even today patients forget that they harm themselves by not following their doctor's advice. AI could remind them of the relevant recommendations.

Providing healthcare services in the e-health era can be a hybrid of live doctor contact and algorithm, and this requires setting both clear organizational rules and defining the rights and responsibilities for both parties to the process. Accountability involves also independent and impartial bodies supervising and monitoring the use of AI in public and private medical facilities. I believe this should be constituted in the future so that AI is subject to scrutiny. Indeed, it is also of great significance when viewed from the perspective of national security and potential cyber threats.

ANETA SIERADZKA

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Over the past few weeks, I have met with more than a dozen Polish entrepreneurs from the tech industry, offering artificial intelligence solutions for medical diagnostics. One of the biggest challenges the industry faces today is to be able to legally obtain the medical data necessary to shape algorithms, which directly impacts their effectiveness. Reliable processing of such data requires awareness on the part of patients, which is still at a low level due to insufficient confidence in digitalization. Without access to local, large, and well aggregated databases, taking full advantage of the potential of AI mechanisms in the medical sector will never be possible. Making use of information resources from other parts of the world may simply not be enough here.

**Maciej Kawecki, PhD** – president of the Stanisław Lem Institute, dean of the Faculty of Innovation and Entrepreneurship at the WSB University in Warsaw, legal counsel at the Maruta Wachta Law Firm, host of the "Technicznie Rzecz Biorąc" podcast run by Onet and Komputer Świat, and author of a tech-focused series aired by Dzień Dobry TVN.

Example of application

# Anonymization for the masses

Tomasz Jaworski

## → The solution provided by BlueAI (Blue.GDPR) uses artificial intelligence (AI) to automatically recognize and anonymize patient data

The Tirol Kliniken network (until 24 June 2015 TILAK – Tiroler Landeskrankenanstalten GmbH) was founded in 1991 and is the largest and most diverse healthcare provider in western Austria. It owns and runs various facilities in Tirol, providing many essential healthcare services. As group supervisor, Tirol Kliniken GmbH operates and coordinates the work of individual clinics.

Tirol Kliniken GmbH has almost 8,550 employees, provides 115,000 inpatient and 1.1 million outpatient services, and performs 65,800 individual surgeries per year. The clinic has 2,500 beds with an average occupancy rate of 80%. With such a scale of operation, a huge amount of medical and diagnostic data is generated, and these must be easily accessible to authorized persons and strictly protected against unauthorized access – as sensitive patient data.

At the same time, medical data is an essential resource for conducting scientific research and participating in research grants. Most of the data identifying the patient is not necessary in the case of searching for population and statistical correlations – for scientific purposes, medical records are subject to the so-called anonymization.

### MEDICAL DATA IN POLAND

In mid-2021, the President of the PDPO adopted the "Industry Code for the Healthcare Sector", presented by the Polish Hospital Federation[1]. The document describes the rules for sharing patients' personal data included in medical records in accordance with the GDPR. It aims to make the application of the regulation easier and to adapt it to the specific nature of healthcare. The subject of the Code are provisions tailoring the obligations of controllers and data processors under the GDPR to the risk of violation of the right or freedom of natural persons, which may be caused by the processing of such data.

The guidance contained in the Code is a direct result of the demands of the scientific community to enable research, grant participation, and data-driven collaboration.

Becoming familiar with Tirol Kliniken's experience is important in order to be able to successfully implement the recommendations of the Code in compliance with the GDPR in practice. The provisions of the Code are simple guidelines, but the amount of work required to anonymize medical records can be disproportionate to the resources and staff required and available.

## SIMPLIFIED PROCESSES WITH BLUE.GDPR

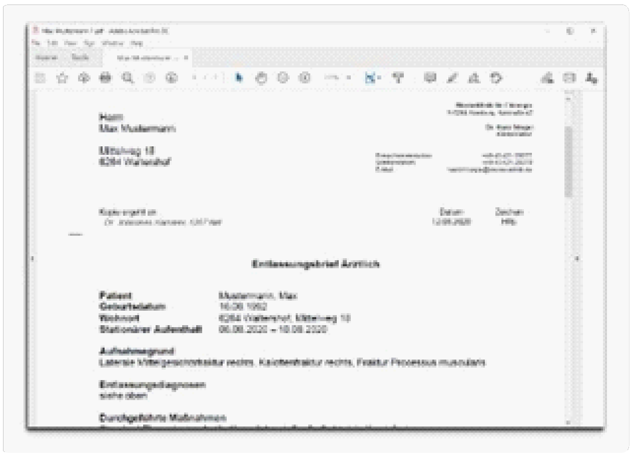
The solution provided by BlueAI (Blue.GDPR) uses artificial intelligence to automatically recognize and anonymize patient data.

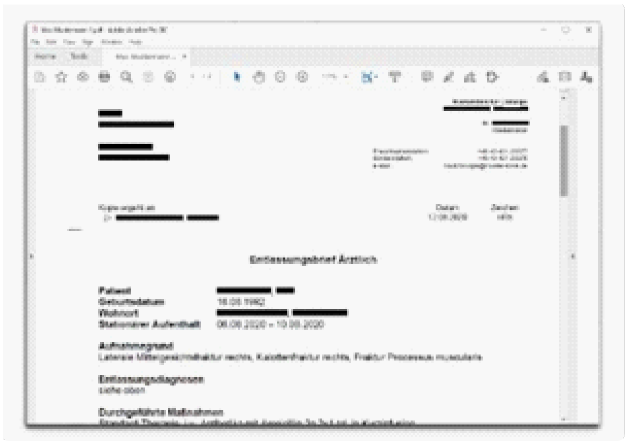
By using a comprehensively trained but constantly learning algorithm, Blue.GDPR very accurately recognizes patient data and makes the data unrecognizable. Medical documents, such as hospital discharge, the personal data of patients, doctors, and staff, as well as diagnostic reports are no longer anonymized manually, but automatically.

This way, the standard of the TGF (Tyrolean Health Fund, Tiroler Gesundheitsfonds) can be maintained – and patient privacy protected.

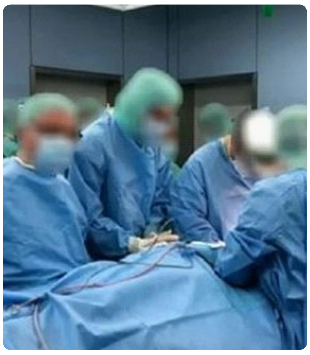
The solution makes it possible to anonymize all types of data used in medical records: documents, images, videos, DICOMs[2], notes, and audio files.

Here's an example of how Blue.GDPR's artificial intelligence works to automatically anonymize documents, text or images:




Sensitive data in videos and images can also be anonymized. The example below shows how the automaton blurs the faces visible in the photo. Preserving the original asset makes it possible to access the source data *ex post* if necessary. However, the rapid exchange of data within collaborative teams is not slowed down by the need to comply with the GDPR. The requirements of the GDPR are met and data can be shared following all procedures and laws.



## CHALLENGES AND BENEFITS

Tirol Kliniken specified detailed requirements for which artificial intelligence had to be trained to anonymize only selected patient data and ignore certain important information so that it remained visible. Since these were medical documents, it was also important to properly train the algorithm for the particularities of e.g. specific medical terminology. As Pietro Lucillo, IT Project Manager at Tirol Kliniken, said: "The constantly increasing need for anonymization turned out to be a time-consuming manual process. With the intelligent software solution Blue.GDPR, we can handle this special requirement more efficiently and thus relieve our personnel"[3].

The benefits include time savings of about 40 hours for anonymizing 100 documents, 60% higher anonymization accuracy compared to the manual process, and a lower risk of revealing sensitive data.

The artificial intelligence-based Blue.GDPR solution can be used for mass anonymization in e.g. the following cases:

- anonymization of documents in reports to supervisory authorities;
- exchange of data between research entities or service providers;
- sharing medical records, such as recordings, at the patient's request while maintaining the privacy of other persons;
- Big Data analytics and the use of artificial intelligence with assurance of privacy and protection of sensitive patient data.

The staff involved in compiling and sharing medical records have welcomed the solution with great satisfaction, as it has relieved them from onerous and tedious tasks. The return on investment period was 6 months.

Blue.GDPR technology is also used in the VSI Holomedicine 3D visualization solution – it makes it possible to anonymize e.g. patient data from DICOM files, for instance. This solution has been spoken very highly of by experts from the Polish network of Clinical Trials Support Centers.

**TOMASZ JAWORSKI**

*(The author's profile is included in Chapter I.)*

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# Chapter V.

# Recommendations

**Key recommendations of initiatives to increase the potential of artificial intelligence, robotics, and related technologies in health care:**

- ensuring an appropriate and proportionate regulatory framework to promote legal certainty and encourage innovation, either by drafting a law on AI in the health sector, which would comprehensively regulate the principles and limits of use thereof, thus unifying the fragmented legal norms in various legal acts, or by comprehensive legislative amendments: developing a plan for simultaneous amendment of the laws adapting the regulations to the needs of AI (e.g. Patients' Rights and Patient's Ombudsman Act, Act on the Profession of Medical Doctor and Dentist, Act on Healthcare Services Financed from Public Funds, Act on Computerization in the Healthcare System, and a number of other regulations governing the provision of healthcare services),
- regulating telemedicine – including remote monitoring,
- helping companies to assess and confidently respond to regulatory requirements and risks as they innovate and grow their businesses based on innovation that minimizes burdens and red tape,
- increasing the availability of sources of funding and of flexible financial instruments to support innovation, as well as providing tools to assess the effectiveness of innovation and implementing reimbursement mechanisms to ensure universal and equal access to these solutions,
- creating AI pilot programs for medical facilities operating in both public and private sector,
- establishing a permanent and independent advisory council for AI in the health sector at the Minister of Health as an advisory and consultative body composed of experts-practitioners in many fields,
- creating a unit for AI and patients' rights at the Patient's Ombudsman and guidelines for the Patient's Ombudsman (artificial intelligence is a potential violation of patients' rights in the digital area, e.g. the patient's right to respect for their dignity, right to confidentiality, equality, access to information and documentation granted to the patient or persons authorized by the patient; AI, however, carries also a risk of abuse of access to patient information by unauthorized bodies and services),
- amending the Medical Code of Ethics, as well as involving non-governmental organizations (NGOs) for patients in the process of building digital awareness among patients,
- involving businesses in building the digital awareness of e-health among Poles as part of their CSR initiatives,
- building public confidence in artificial intelligence, robotics, and related technologies, and promoting healthcare management based on technological, process, and organizational innovations utilizing advanced digital technologies and computational methods,
- changing the curricula of medical students and specialist registrars (doctors training for their specialization) and the curricula of other medical professions, taking into account the subject of e-health and issues such as AI, big data, cybersecurity, GDPR; today, the education in law among doctors is at a marginal level and in no way takes into account the needs and challenges faced by practicing doctors in the era of e-health,
- raising the legal awareness of physicians and other medical professional groups: information and training programs for medical professionals in the field of e-health (rights and responsibilities of the physician, patient, institution, principles of safe use of digital tools while hospitalizing patients),
- developing a code of good practice for the physician in cyberspace (online/phone consultations, online meetings and lectures as well as activity on social media carry a risk of numerous potential violations in the area of ethics and professional secrecy; the current legislation in this area and the legal awareness among physicians are not at a sufficient level),
- reinforcing the security of health data in terms of restricting access thereto to the insurance sector and employers,
- building strategic partnerships with digital service providers.

# Appendix – Glossary

**Artificial intelligence** – the result of machines, especially computer systems, imitating the processes that characterize human intelligence. In other words, artificial intelligence is the science of how to produce machines equipped with some features of the human mind, such as the ability to understand language, recognize images, solve problems, and learn[1].

**Econometric model** – a formal description of the relationship between a specific quantity, phenomenon or course of economic process and factors which shape it, expressed in the form of a single equation or a system of equations[2].

**Statistical models** – a hypothesis or a system of hypotheses, formulated in a mathematical way (in the form of an equation or a system of equations, as appropriate), which represents the fundamental relationships occurring between the real phenomena under consideration. [wiki]

**Machine learning** – a branch of artificial intelligence, in which programs automatically modify their knowledge and procedures to improve their performance. The programs work here instructed clearly by their teacher, using training examples, tests, or program-generated experiments. Machine learning enables computers to deal with new situations through analysis, self-learning, observation, and experience[3].

**Deep learning** – it is a subset of machine learning, based on artificial neural networks. The process of learning is *deep* because the structure of artificial neural networks consists of multiple input, output, and hidden layers. Each layer contains units that transform input data into information that subsequent layers can use to perform some predictive task. Thanks to such a structure, the machine can learn using its own data processing[4].

**Neural networks** – structures consisting of neurons connected by synapses. Artificial neural networks consist of three types of layers: input (collecting data and passing them forward), hidden (looking for connections between neurons, which makes the learning process occur), and output (collecting conclusions, the results of the analysis). A neural network can consist of any number of layers. Neural network technology has many practical applications. It is used for handwriting recognition for check processing, speech-to-text transcription, weather forecasting, and face recognition, among others[5].

**Supervised learning** – a type of learning in which a human instructor provides examples for training and is responsible for the correct classification of the examples provided[6].

**Unsupervised learning** – a type of learning in which data points have no labels – the algorithm labels them on its own, organizing the data or describing their structure[6].

**Reinforcement Learning** – a field of artificial intelligence, which is about achieving a goal in an uncertain, potentially complex environment. Artificial intelligence is faced with a game-like situation: through trial and error, the computer searches for a solution to a given problem. In order for the machine to do what the programmer expects it to do, it is either punished or rewarded for the actions it performs. However, apart from punishments and rewards, the programmer does not provide the machine with any guidance or suggestions[7].

**Regression** – a type of supervised learning where regression algorithms predict the value of a new data point based on historical data[8].

**Classification** – a type of supervised learning where classification algorithms use predictive computing to assign data to preset categories[8].

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