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The digital transformation of Czech healthcare: trends and COVID-19 impact

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Abstract: The COVID-19 pandemic has placed an enormous burden on healthcare systems. The pandemic revealed insufficient digitalisation of Czech healthcare, particularly in terms of interconnectedness of healthcare systems. Before the pandemic, the digitalisation of healthcare was not a priority; thus the E-health Act is still absent. Paperless healthcare was only represented by e-prescription (eRecept) and electronic sick note (e-Neschopenka), with tracking application e-Rouska and electronic medical request for COVID testing (eZadanka) introduced in 2020. The pandemic is expected to accelerate the digitalisation of Czech healthcare supported by funds from the National Recovery Plan. Nonetheless, several projects have been postponed with healthcare priorities being identified elsewhere. Based on a novel approach we analysed emerging medical-related technologies (keywords) in research output (publications, projects, contractual research, patents) among Czech research institutions and firms. In the last decade (2009–2018), the most frequent new technologies (keywords) were those related to genetics (genomic and genetic sequencing), nanomaterials (nanoparticle and nanomedicine), e-health (data processing), and sensors necessary for IoMT. In terms of future business opportunities big data, AI/machine learning and IoMT/wearables are considered to be the three principal transformative digital technologies.

Keywords: e-health; electronic health; healthcare digitalisation; Czech healthcare; COVID-19; digital transformation; Czechia.

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1 Introduction

New technologies are transforming all economic sectors. Even though healthcare has been lagging behind other sectors in terms of digitalisation, there are several disrupting technologies with the potential for remarkable change. For successful digitalisation, functional e-health is necessary, but the list of transforming technologies is much longer and includes big data and AI, virtual and augmented reality, 3D print, internet of (medical) things, robots, nanotechnologies, genetics, telemedicine, and many others.

There have been many challenges for the healthcare sector such as rising costs and aging populations (Christensen et al., 2000; WEF, 2019). The healthcare sector was going through a transformation in the pre-pandemic times, but the COVID-19 pandemic has speeded up the digitalisation of healthcare radically (Peek et al., 2020). Although digitalisation has progressed in most sectors, healthcare has attracted unprecedented attention.

The paper aims to evaluate the digital transformation in Czech healthcare in the pre-COVID period and the changes introduced during 2020. We base our findings particularly on semi-structured interviews among Czech firms/researchers/officials supplemented with information from healthcare data, reports, and news. Furthermore, with a novel approach, we identify how emerging healthcare technologies are represented in research output (publications, projects, contractual research, and patents) among Czech researchers in public organisations and firms. This paper contributes to the general findings on digitalisation in healthcare by providing evidence on the situation in a new EU member state.

The paper is divided into four main sections. Firstly, a brief literature review demonstrates the sector's main characteristics, recent trends, and technological developments. Following that, the extraction of research data and the research methodology applied are explained. The analytical part of the paper considers the actual situation in Czechia, including existing regulation, analysis of promising technological areas related to healthcare, as well as the state of digitalisation before the COVID pandemic and how the pandemic affected the digitisation. In the conclusion, the major findings from the paper are summarised.

2 Literature review

Digitalisation has been ongoing for several years and will have a major impact on all sectors including healthcare. Due to the healthcare sector specifics, such as high regulation (Mwachofi and Al-Assaf, 2011; Imison et al., 2016) and the complexity of the sector (Haggerty, 2017) the digitalisation has been slower than in many other sectors (Herrmann et al., 2018). Nonetheless, the COVID-19 pandemic has accelerated the whole process.

Digitalisation (or digital transformation) includes the acquisition of digital assets, new strategies as well as changes in organisational structures (Verhoef et al., 2019). It relies on many specific technologies from big data, AI, and the internet of things (IoT) to robots. In this paper, healthcare digitalisation covers particularly electronic health records (EHR), telemedicine (or telehealth), monitoring equipment including wearables, big data and AI, web and cloud-based tools, electronic communication, virtual reality, though, we also cover technologies such as genetic sequencing or 3D. Amore specific definition of

the ER term 'e-health' is also widely used which according to European Commission (2012) includes telehealth, EHR, online prescription, and health information systems.

Digitalisation aims to improve productivity as well as the quality of care. Misdiagnosis or prescribing errors occur in 10%–15% of cases (Berner and Graber, 2008; Lewis et al., 2009). The digitalisation requires structural reorganisation of the whole medical sector which is both time and financially demanding. It also brings new actors from other fields, particularly IT, though stringent regulation makes it more difficult for new entrants to access the market and compete with established players. Digitalisation also leads to convergence between pharmaceutical, medical and/or ICT products – a challenge in terms of regulation (e.g., hospital beds performing diagnostic tasks and applying drugs). Digitalisation of healthcare data stemming from record-keeping, compliance, and regulatory requirements is associated with the implementation of EHR or electronic medical records (EMR) with current and historical patient information. For a successful implementation, appropriate software needs to be chosen, providing training and real-time support for staff is also crucial (Boonstra et al., 2014; Cresswell et al., 2013). In addition, the systems need to be unified or at least provide interoperability at the national and possibly also at the EU level. The EMR is also a significant financial burden for healthcare systems (Agnihothri et al., 2020).

Patient data can be used to predict medical risks, the so-called predictive analytics using AI and big data (Imison et al., 2016). This is dependent on the amount of data as more datasets increase the accuracy (Billings et al., 2013). AI has already been used for supporting diagnostics (e.g., skin cancer detection). Nonetheless, AI also commits errors; therefore, its combination with a human factor might yield a better result. Another trend strengthened by the pandemics is telemedicine/telehealth often connected with using specific applications or wearables (Go Jefferies et al., 2021). Virtual/extended/augmented reality can help remote diagnosis, though it is also used for surgeries and training (Negrillo-Cárdenas et al., 2020).

Other technologies associated with the digital transformation of healthcare include nanotechnologies used for carrying drugs or specific nanoparticles, drones for delivering drugs, vaccines, and medical aids during disasters or medical emergencies, or surgery robots. 3D printing is used for prosthetics, tailoring drug dosage (Zidan, 2017) and tissue printing (often called bioprinting). Devices using IoT or the internet of medical things (IoMT) are steadily increasing, in 2019 there were over 320 thousand health applications available worldwide (WEF, 2019). Even genome sequencing is speeded up with digitalisation and leads to a growing interest in precision (or personalised) medicine.

In general, digital technologies in healthcare increase efficiency and quality (Laurenza et al., 2018), but their implementation can be accompanied by specific inefficiencies, and possibly threaten the quality of care. Further, questions are related to inequality in access to healthcare services, ethical questions, changes in the relationship between patient and doctor, the security of health data and establishing standards and governance (Priyanka and Kulennavar, 2014; Peek et al., 2020). The privacy of one's personal health information is the primary concern of the public (Anderson and Agarwal, 2011). Access to health data by unauthorised persons is undesirable, especially the misuse of data by a subject without permission, be it an insurance company, employer, or

anyone else (McFall, 2019). Healthcare was the fifth most targeted industry when it comes to cyberattacks in 2016, with more than 16 million patient records stolen from healthcare organisations in the USA (Snell, 2017).

The coronavirus-caused respiratory disease COVID-19 has spread globally in winter 2020 and the first case in Czechia was announced on 1 March 1 2020. As of early May 2021, more than 150 million confirmed cases were recorded globally with over 1.6 million cases in Czechia (WHO, 2021). Commonly applied measures to tackle the spread of the virus included quarantine measures, contact tracing, social distancing and the wearing of face masks (Anderson et al., 2020). Digital technologies have been applied for tracking contacts and sharing data. Further, big data in combination with AI is being used for the modelling of viral activity and public health planning along with the development of drugs and vaccines (Vaishya et al., 2020), facial recognition companies have enabled the identification of people with elevated temperatures (Ting et al., 2020) and chatbots are applied to answer the most common questions (Miner et al., 2020). Nonetheless, usage of AI for COVID-19 diagnosis and prognosis is problematic due to the limited accuracy of the models (Wynants et al., 2020). Digital technologies have also been used for remote diagnosis (Robbins et al., 2020), and some countries even relaxed privacy and data protection regulations for telemedicine/telehealth (Peek et al., 2020).

In Czechia, healthcare expenditure accounted for 7.5% of GDP in 2018, below the OECD average of 8.8%. Nonetheless, Czechia had the fourth-highest share of public financing (82.4%) in the EU in 2015 (OECD, 2019) as the Czech healthcare system is mostly financed by public health insurance, which provides general coverage with a generous array of paid services. The Euro health consumer index ranked the overall healthcare performance of Czechia 16th out of 35 countries in 2017 reaching the level of the UK and Spain, which is a remarkably good result given the country's healthcare spending expressed in purchasing power (Björnberg, 2018). The most significant problems the Czech healthcare system currently faces are the unfavourable age structure of the doctors, persisting disparities in the numbers of health professionals across regions, and the brain drain among young doctors. Further, capital investment in the health sector is the lowest in the EU (OECD, 2019). Despite that, the Czech Republic has emerged as a favorite European destination for medical tourism as well as for studying medicine.

There are several overview papers on the digital transformation in healthcare from the business perspective (Agarwal et al., 2010; Marques and Ferreira, 2020; Kraus et al., 2021), though country-level assessment is less common. In Czechia, there are several studies related to healthcare and health policy (e.g., Rokosová et al., 2005; Lawson and Němec 2003; Gulácsi et al., 2014). A study by Seddon and Curie (2017) assessed e-health in EU countries and Czechia was among the followers (the second group of three) in terms of e-health together with countries such as Germany and Austria. Some basic information on computerisation in healthcare in Czechia can be found in Sovová (2019) and Laus (2017). Bruthans (2019) mapped the ePrescription in Czechia. To a limited extent, underlying trends related to medical technology have been outlined in other papers (Vlčková, 2019; Vlčková and Thakur-Weigold, 2019). This research is thus novel regarding the insight into occurring and upcoming technological changes in the Czech healthcare sector.

3 Data and methodology

In this paper, we combine qualitative surveys and quantitative analysis. The qualitative surveys map the digitalisation of Czech healthcare, especially the extent of digitalisation, limitations and the COVID-19 impact. The quantitative part enables the identification of emerging healthcare technologies in which Czech firms and research organisations have been the most engaged.

The qualitative part of the paper was based on 14 semi-structured interviews conducted in local companies, research institutes, and the public sector that were either identified as digital healthcare innovators or engaged in the digitalisation of healthcare. Ten interviews were conducted in the spring of 2019 and four interviews in spring 2021 to include the effects of COVID. The purpose was to gain an insight into the topic of digitalisation in Czech healthcare from relevant respondents in an approximately one-hour personal or online conversation. An array of open-ended and closed questions formed the basis of the semi-conducted interviews, where the underlying motives for respondents' answers were also usually tapped into (Newcomer et al., 2015).

For the assessment of prospective technological areas related to healthcare in Czechia, we apply a novel approach. We work with data on Czech R&D results, predominantly with data on publications, scientific projects, contractual research, and patents of Czech inventors. Patent data were obtained from the Orbit Intelligence database (Questel, 2019)[1], data on publications, projects, and contractual research are from a national database on R&D and innovations supported through Czech public funds (RVVI, 2019). Based on studies on digitalisation and Industry 4.0 we identified over 290 keywords (KWs) covering new technological topics. We did not only consider topics related to healthcare, as there are many more industries primarily oriented towards tackling sector-specific tasks and challenges, while, simultaneously contributing to the advances in healthcare as well (e.g., sensors). We searched for all these keywords in titles, abstracts, and keywords of scientific output. We explored the scientific results covering the period 2009–2018 to ensure the analysis is focused on the most recent technological development. The hypothesis was that the higher the number of KW found in patents, projects, publications, and contractual research, the more significant the trend for the given technology in digital healthcare is in Czechia. We also evaluated the first and second periods (2009–2013, 2014–2018) to observe the trend.

To identify results related to healthcare, we applied the following procedure: we considered all scientific outputs under the medicine category (in the case of patents we included categories A61 – medical or veterinary science; hygiene). Also, we added all further results in which medical institutions or medical firms participated. Lastly, we included all research outputs which entailed keywords related to the healthcare sector. Subsequent manual clearing removed outputs not associated with the healthcare sector. In the end, we obtained 5,952 scientific outputs, namely 367 patents, 4,644 publications, 909 projects and 32 items of contractual research that included 7,069 keywords from the list (see Table 1). Many outputs include more than one KW from our list of circa 290 and were included in our selection. On average every output included 1.25 of these KWs. In general, patents contain more keywords than publications or projects. The average number of KW per patent is 2.85. Therefore, we analyse the trends in patenting separately.

Table 1 List of scientific output in the selection

	Patents	*Publications*	*Projects*	*Contractual research*	*Total*
Scientific outputs	367	4,644	909	32	5,952
Keywords	1,009	4,876	1,147	37	7,069

Source: Questel (2019) and RVVI (2019)

Based on information from interviews and data we were able to identify what digital trends are present in the Czech healthcare system and the impact of COVID-19 and which technological areas related to healthcare have the most significant potential in terms of research/innovation.

4 Digitalisation in the Czech healthcare sector

We first analyse the data on emerging technologies from research outputs. Then, we assess the overall digitalisation of Czech healthcare based on interviews, media news, and official governmental reports.

4.1 Emerging healthcare technologies among Czech firms and research institutions

The analysis of keywords in scientific output throughout 2009–2018 enabled us to identify the most frequently mentioned technologies as well as those which are on the rise. We found that the most common keywords related to emerging (technology) trends include genomic, 3D, tissue engineering, gene therapy, laser and surface treatment among others (see Table 3). There are differences between the occurrence of technologies (KWs), the more technical ones, are more frequently in patents, (e.g., nanoparticle, surface treatment, data processing), whereas KWs such as genetic sequencing are especially found among publications. The majority of patents were filed under WIPO or EPO patent offices reflecting that the invention is considered to have potential on foreign markets. Apart from the medical category, publications/projects/contractual research was also listed under biological or engineering studies and chemistry. In terms of patents, the second most represented category after A61 – medical or veterinary science; hygiene was class C07 – organic chemistry.

We also examined the trend – technologies that have increased the most (with a minimum of ten occurrences). Among the most rapidly increasing technologies belong CRISPR; machine learning and energy storage (see Table 3). In section two, major technologies responsible for transforming the healthcare sector were identified. Although we cannot directly measure the impact of these new technologies/approaches with the number of keywords, we can use it as a form of proxy. It does not necessarily mean that Czechia does not have capabilities in other areas; they just do not yet happen to be reflected significantly in the healthcare-related areas which were defined as the subject of this study. We can see that many of these transformative technologies have increased, though the overall numbers are still rather small. These include particularly areas related to AI and big data (machine learning, big data), nanotechnologies (nanomaterial, nanoparticle, nanofibres), genetics (CRISPR, genetic engineering) and e-health (e-health, data transmission, data storage, information sharing). Sensors as an integral part of

IoT/IoMT, which are crucial for remote diagnosis, are also frequent and further increasing.

Additionally, in the case of patents, we can compare the occurrence of KWs among all patents worldwide applied for by Czech inventors and investors from other countries. This shows that in big data as well as AI, machine learning, nanofibre, and electron microscopy Czech investors are relatively stronger compared to other technologies (KW). These are also KWs with the biggest relative increase between 2019–2013 and 2014–2018.

Table 2 Most frequent KWs in scientific output

Keyword	*Patents*	*Publications*	*Projects*	*Contractual research*	*Total*
Genomic	19	441	124	1	585
3D	37	322	87	3	449
Tissue engineering	28	247	59	3	337
Gene therapy	49	253	64	1	367
Laser	34	339	17	2	392
Surface treatment	72	143	31	1	247
Medical imaging	5	204	38	2	249
Data processing	32	141	32	6	211
Sensor	80	100	19	2	201
Genetic sequencing	7	110	67	0	184
Cell biology	18	105	74	0	197
Molecular diagnostic	17	122	54	0	193
Electron microscopy	8	188	21	0	217
Simulation	12	187	15	0	214
Medical equipment	31	87	34	1	153
Nanoparticle	30	50	20	0	100
Biomedical engineering	10	122	26	0	158
Signal processing	23	67	14	0	104
Nanomedicine	0	77	6	0	83
Targeted drug delivery	14	58	9	0	81

Source: Questel (2019) and RVVI (2019)

When we focus on specific actors, we can again identify significant variations between research outputs from RIV (publications, projects contractual research) and patents. In terms of research outputs from RIV, the majority is undertaken by universities, institutes of the Czech Academy of Sciences, and university hospitals.[2] Here, the most prominent entity with the highest output is the First Faculty of Medicine at Charles University, followed by the Faculties of Medicine at Masaryk University and Palackého University (see Table 4). Apart from medical faculties, we can find the Faculty of Biomedical Engineering among the top ten. Scientifically significant contributors among hospitals

include the Motol University Hospital, the University Hospital Hradec Králové, and IKEM. In post-communist countries, traditionally, academies of sciences are of great scientific importance. In Czechia, the Institute of Physiology, Molecular Genetics, and the Institute of Experimental Medicine play a crucial role. Switching our attention to patents, we observe private companies dominating, particularly Zentiva (pharmaceutical firm), Contipro (hyaluronic acid producer), and Linet (hospital bed producer). The Czech Academy of Sciences, Charles University, and the Czech Technical University are other important patent applicants (a detailed breakdown into faculties is not always available).

Table 3 Most rapidly increasing KWs

Keyword	*2009–2013*	*2014–2018*	*Increase in percentage points*
CRISPR	1	11	1,044
Machine learning	4	25	550
Energy storage	8	26	238
Hydrophobic coating	5	13	170
Big data	6	15	160
Nanomaterial	5	12	150
Nanoparticle	31	69	131
Nanofibre	25	50	108
Virtual reality	12	23	99
Targeted drug delivery	28	53	97
Nanomedicine	29	54	94
Surface treatment	97	150	61
Data transmission	30	46	59
Laser light	16	24	56
Genetic sequencing	74	110	55
Tissue engineering	137	200	52
Data storage	25	33	37
E-health	36	45	30
Information sharing	12	15	30
Sensor	90	111	28

Source: Questel (2019) and RVVI (2019)

Relating keywords to specific entities provides another insightful perspective. Whereas medical schools and hospitals mostly focus on topics such as laser, genomic or 3D, in the case of the Faculty of Biomedical Engineering the top three KWs include simulation, laser, and medical equipment. In terms of patents, the KWs are much more varied based on the applicants' field of business. To illustrate, Contipro focuses mostly on nanofibres, tissue engineering, and targeted drug delivery, the Czech Academy of Sciences on genetics, whereas Charles University files for patents related to sensors, machine learning, or simulation.

Table 4 Major institutions/patent applicants in research output

Institution – publication, project, contractual research	*Most frequent KWs*	*Publication, project, contractual research*
Charles University – first Faculty of Medicine	Genomic, 3D, laser	579
Masaryk University – Faculty of medicine	Laser, genomic, 3D	395
Motol University Hospital	Genomic, gene therapy, molecular diagnostic	278
Palackého University – Faculty of Medicine	Genomic, 3D, laser	252
Czech Technical University in Prague – Faculty of Biomedical Engineering	Simulation, laser, 3D	225
Charles University – third Faculty of Medicine	3D, laser, CAD	156
University Hospital Hradec Králové	laser, molecular diagnostic, genomic	127
St. Anne's University Hospital	3D, genomic, laser	126
Institute for Clinical and Experimental Medicine (IKEM)	Laser, gene therapy, 3D	124
General University Hospital in Prague	Gene therapy, genetic sequencing, 3D	113
Applicant – patents	*Most frequent KWs*	*Patents*
Zentiva	Programmable matter, data protection, 3D	28
Academy of Science Czech Republic	Gene therapy, genomic, cell biology	27
Contipro	Nanofibre, tissue engineering, targeted drug delivery	25
Medical Instill Technologies	Sensor, energy storage, surface treatment	14
Linet spol. s.r.o.	Sensor, medical equipment, data transmission	12
Charles University	Sensor, machine learning, simulation	12
Czech Technical University in Prague	Sensor, laser, data transmission	9
Robotsystem	Robotic, electric motor, medical robot	9
BTL Holdings	Sensor, surface treatment, laser light	7

Source: Questel (2019) and RVVI (2019)

4.2 Digitalisation and the COVID-19 impact

In Czechia, several initiatives related to e-health have been introduced. The first unsuccessful attempt was electronic health books (so-called IZIP), which started in 2004.

These health books had around 2.5 million clients and stored over 250 million health records in total, but the project was terminated in 2012 as a result of financial irregularities and a suspicion of criminal activities (Otevřené zdravotnictví, 2018) and harmed the progress in healthcare digitalisation. Electronic prescription (eRecept) has been operating since 2011 on a voluntary basis, and since 2018 it has become mandatory and fully functioning (Bruthans, 2019). In 2020 eNeschopenka was introduced, this obligatory system electronically connected doctors, employers and the Czech social security, thus the insured person would not have to hand over documents to an employer personally. Other existing digital solutions are especially targeted at the exchange of healthcare data between healthcare providers, such as ePACS (visual medical records), eZpráva (a secure e-mail provided by a private entity) or NIX-ZD (cross-border e-health services). The European mechanism for the exchange of medical data (patient summary) is being implemented.

According to expert opinions, Czechia is lagging behind other European countries in terms of digitalisation, though they also stress that complete digitalisation of healthcare has not been achieved anywhere, yet. Seddon and Curie (2017) found Czechia a follower (a second group of three) in terms of e-health. Nonetheless, the lag has increased in recent years. There is a big variation across the specific areas of digitalisation, though. On the one hand, we have high quality medical registries; on the other hand the access of patients to their medical records is missing. Overall, paperless healthcare has not been implemented, yet.

One of the major reasons for the current situation is that healthcare digitalisation has not been a real governmental priority. Limited financial and human resources in particular, have disabled further progress. ‘Changes are driven by events rather than a plan’ as one respondent put it. This is reflected in the fact that the E-health Act has not yet been approved. The E-health Act is currently in the comment procedure, though the unified standards are about to be implemented by 2030. By then, every citizen should have a shared electronic medical record, the systems should be interconnected and data automatically collected (Zeman, 2021). Earlier terms recommended by the ministry where opposed by the Czech medical association, claiming that the technical skills of many doctors and particularly the complexity of implementation of new medical systems including the costs (expected to be around 4 mil EUR per hospital) and requisites of the selection procedure disallow earlier implementation. Major comments are attributed to privacy or cyber security issues and the limited attention given to telemedicine (Vejvodová and Novotný, 2020).

According, to some business representatives, the other reason for the limited efforts in digitalisation is that we have high quality healthcare, which does not push towards digitalisation. Economic incentives are also lower than in many other EU member states. Digitalisation of healthcare is further hampered by GPs (particularly eRecept, eNeschopenka), though they are often forced to use imperfect solutions. Nonetheless their reluctance to invest in new technologies and learn with new systems has been largely reduced by the pandemic (see below). Wider implementation of e-health also means greater control over GPs, which is so far very limited. The non-existence of one unified data standard is another significant barrier.

Overall, the state does not have a clear vision of what e-health should look like (also due to discontinuity between ministers), does not implement best practices and does not support innovation among the healthcare providers (hospitals). Since the majority of hospitals is state owned, economic motives are limited. Cooperation between hospitals is

also not supported, as was shown in the case of one Prague hospital offering their IT solution for free to other hospitals. In the end, this was not allowed because, if civil servants develop something with state funds, they cannot give it to anyone outside the hospital for free as this could be considered as the theft of public property (Sedlák, 2020). IT departments in hospitals are another a big issue. Most of the systems are custom made, old and not interconnected.

4.2.1 Business perspective

The fragmented system and small size make Czech healthcare unattractive for foreign companies providing e-health solutions. Most foreign medical software providers had already entered the Czech market and subsequently left it. The majority of the software providers are thus local companies with limited space for innovation. Low interoperability between the IT systems curbs further improvements.

In Czechia, innovative solutions are in general not financed by health insurance companies and even when such activities become a part of the reimbursement ordinance they cannot be financed retrospectively. Location-related disadvantages thus lead some innovative companies to do business abroad solely (e.g., Germany) and Czechia could be penetrated afterwards as a complementary market. On the other hand, enormous potential for new business solutions stems from a small market (less competition, less diverse customer needs) which is easier to penetrate and operate in, as well as the possibility of access to high-quality healthcare and healthcare professionals. The insufficient level of digitalisation provides another significant stimulus for healthcare players to engage. Considerable potential lies principally in the area of telemedicine and EHR, as Czechia is still falling behind in these fields. Across the experts, the views on who should be the driver of digitalisation differ. Some say, it should be the patient, others point out economic motivation. In general, Czech patients have low health literacy (Sovová, 2019) and patient organisations do not function well.

Possible threats to success on the market also result from the market's limited potential and a prevalent general distrust towards digital technology. For producers and distributors of active medical devices, the process of new device approval is viewed as very demanding, with the principal competent state authority (SÚKL) putting 'incomprehensible requirements' on the healthcare players. Other possible obstacles to consider include the separation of the areas of healthcare and social services, lower public funding and transparency, insufficient digital infrastructure, weak patient organisations and uncoordinated lobbying.

Several innovative projects/applications were started by family members trying to help their relatives. Later, they wanted to sell their solutions but they lacked the necessary business acumen. Many such solutions were introduced during the pandemic. Nonetheless, these are fragmented solutions that cannot have a considerable economic and social impact. Profitable solutions need some critical threshold of customers, covering a larger part of the value chain is also an advantage.

Several innovative health-related private and public entities operate in Czechia. The Czech National E-health Centre in Olomouc engages in launching new telemedicine products on the Czech market. This centre is also linked to the first Digital Innovation Hub on Healthcare (DIGI2Health). The Institute for Clinical and Experimental Medicine (IKEM), one of the largest specialised clinical and scientific research centres in the Czech Republic, was the first one to implant a device for remote monitoring and control of a

patient's core heart functions in 2010. They also implemented their own IT system. Other innovative companies include EUC clinics providing digitalised communication with patients. Innovative software providers include ICZ, STAPRO and the international Compugroup medical.

Based on the interviews, the top three transformative technologies that will define the future of Czech healthcare in the following decade are big data and their analysis used among others for structuring unstructured data from health records; machine learning/AI for diagnosis assistance; and IoMT/wearables, which will allow 24/7 monitoring. Other prospective areas for commencing business activities include cloud solutions that will allow GPs administration from home, wider usage of chatbots and augmented reality as well as shared medicine, genetics and biological treatment. A more significant onset of telemedicine stimulated by the pandemic is envisaged (see below). With EU Medical Device Regulation 2017/745 coming into force on 26 May 2021, medical devices software is going to adhere to specific rules (European Commission, 2020; Jarman et al., 2021). This could make the implementation of innovative solutions more difficult.

4.2.2 The impact of the COVID-19 pandemic on digitalisation

The pandemic revealed the low level of digitalisation of healthcare in Czechia. Data-driven approaches are crucial and the Czech healthcare system does not provide real-time data, e.g., on the number of cases, hospitalised patients, or tracing COVID cases. Healthcare systems have so far not been interconnected. As a result, Czech hospitals, ambulances, laboratories, and other medical facilities operate in isolated systems that do not communicate with each other. One of the major barriers is that unified technical standards on how health systems should work and communicate with each other are missing.

Paperless sharing of documentation is rare. In the majority of cases, doctors rely on the patient to pass on medical reports from surgery to surgery. This was impossible in the case of thousands of patients needing medical requests for COVID testing, therefore the system for electronic medical requests was introduced – eZadanka. So far, however, it is still limited to COVID-testing. Furthermore, the National Health Information Portal has been introduced providing the general public with information in the field of healthcare (see https://www.nzip.cz).

During the pandemic, a phone-based application e-Rouska was launched as a part of the Smart Quarantine concept of the Ministry of Health. It notifies its users of risky encounters with infected individuals anonymously. The low willingness of people to use e-Rouska (1.5 million – 17% of adult population) is related to privacy concerns, unwillingness to be traced and quarantined, or just the fact that people do not believe in their full functionality as they are rarely informed about encounters with infected individuals.

Apart from public solutions, companies have also come up with their own solutions. In 2020, significant growth of existing telemedicine companies occurred such as Videodoktor.cz, Doktor do kapsy, Meddi Hub, Lékař online 24/7. For instance, uLékaře a virtual consulting room that connects doctors (already 350 of them) with patients expects to double the turnover in 2020 (Křeč, Holzman, 2021). This has been enabled by the fact that consultations with GPs and other specialists completed remotely have been covered by most health insurance companies since July 2020 (e.g., VOZP, 2020). As the

legislative framework is absent, the Association of General Practitioners has produced a set of recommendations on telemedicine.

Nonetheless, the healthcare system was not to blame for Czechia being one of the most COVID-19 affected counties in spring 2021. Most experts agree that unlike in most other countries, politicians and not experts run the pandemic. The reasons, for the increasing number of cases in autumn and then again in winter were related to the delayed implementation of measures before the election in October, reopening ahead of Christmas, and the late reaction to the new variant emerging in early January; in general the unrecognised strategy of establishing a herd immunity by exposure to the virus (Kottasová, 2021; Hořejší, 2021). Though, evaluation of emergency measures is still to be done.

The COVID-19 pandemic can prioritise digitalisation of healthcare. Several pilot projects have started in the regions, though the central solution is still missing. The GPs are now more open to new solutions including telehealth and telemonitoring. On the other hand, some experts are worried that the pandemic could also slow digitalisation. This is because the major priority is providing care for patients and other projects might be postponed or cancelled. Further, the pandemic causes significant economic problems for healthcare providers. Hospitals are postponing operations and other medical procedures leading to a loss of income from health insurance companies. The so-called compensatory reimbursement decree orders health insurance companies to call outages. To provide money for the health insurance companies, the state had to increase payments for state-insured persons (Holub, 2021). Additionally, it is estimated that it will take at least two years to catch up on medical procedures that had to be postponed due to the pandemic (DeníkN, 2021). Economic reasons might thus be a bigger motivation for digitalisation in the future.

Apart from the law on electronic healthcare, the current priorities of the ministry include guaranteeing cybersecurity, development of e-health standardisation and interoperability of health records, support for telemedicine, and digitalisation of the ministry (Zeman, 2021). Cybersecurity is currently one of the major problems. Though there is an overall increase in cyberattacks, hospital attacks may endanger patients and thus attract more attention. Large as well as smaller and even private hospitals in Prague, Brno and Benešov have been attacked in recent months (Řeháková. 2021). The hospital IT departments lack resources as well as expertise. Some experts believe that state organisations should be assisting hospitals with cybersecurity measures. The Ministry of Health is preparing a cybersecurity strategy for 2021–2025, there is also an initiative Hospital security operation centre focusing on secure information systems in healthcare (https://hsoc.cesnet.cz/). The missing priority of healthcare digitalisation and the costs of digitalisation including cybersecurity are major barriers. Currently, project plans are being prepared for healthcare digitisation, including cybersecurity, for over CZK 310 million Eur, of which CZK 280 billion is through the National Recovery Plan (Zeman, 2021).

5 Conclusions

Digital technologies transform all economic sectors and healthcare is no exception. As healthcare was under extreme pressure, the COVID-19 pandemic revealed many

shortcomings of the whole healthcare system. It is expected, that the pandemic will accelerate healthcare digitalisation. In this paper, we presented the digitalisation of Czech healthcare. The Czech healthcare system is considered to be relatively good. At least in some areas of e-health, Czechia was a medium performer in the European context, though its relative position deteriorated according to expert views.

Over recent years, several digital solutions in healthcare have been implemented, particularly eRecept (electronic prescription) and eNeschopenka (electronic sick note). The COVID pandemic has revealed that the interconnection of health systems is missing, and access to real-time data is causing major problems and limits the possibilities to efficiently deal with the pandemic. The major reason for the lagging healthcare digitalisation is the fact that it has not been a real governmental priority. This was reflected in limited financial and human resources. As a result, the E-health Act has not yet been implemented; though, its first version has been already sent to the comment procedure. The reluctance of GPs to use new technologies, the introduction of imperfect solutions, the highly decentralised healthcare system, and the non-existence of unified data standards represent other obstacles to digitalisation.

The COVID-19 pandemic revealed the existence of unconnected systems that do not provide access to real-time data and make it more difficult to organise healthcare under such pressure. Nonetheless, the reason for the very high number of COVID-19 cases in Czechia is related especially to political decisions based on the availability of medical beds and an unproven strategy of building a herd immunity based on exposure to the virus. During the pandemic, several new solutions were implemented: eZadanka an electronic medical request for COVID testing, and a phone-based application e-Rouska, for tracing COVID cases, although it was not widely downloaded. Telemedicine increased rapidly, which can also be attributed to the increased willingness of doctors to consult remotely and especially the fact, that this service started to be covered by most health insurance companies. It is not yet known if the pandemic will speed up digitalisation of Czech healthcare. On the one hand several new projects started, and GPs are now more open to new digital solutions. On the other hand, some experts are worried that the pandemic could slow the development of healthcare digitalisation, because the main priority has been providing care for patients, some projects might be postponed or cancelled and due to the enormous costs of the pandemic sufficient finance may no longer be available. Hospitals are now also dealing with more cyberattacks.

Several steps need to be implemented in order to digitalise Czech healthcare. A specific concept needs to be chosen (centralised or decentralised), data standards set and best practices from other countries should be implemented, since this has not been the case so far. There has neither been a society-wide nor political debate over the form of e-health. That requires initiatives to secure a well-developed IT infrastructure based on a functioning EHR system for medical data record-keeping and sharing with ensured interoperability. Furthermore, a final version of the E-health Act needs to be adopted to provide a basic legal framework for subjects to operate within. Other possible areas for improvement include increasing the number of categories covered by healthcare insurance companies, and a change in the mindset of many healthcare stakeholders. Nonetheless, according to expert opinions, Czech healthcare will succeed in achieving complete digitalisation, including the enabled transfer of electronic patient data during this decade. EU programmes/resources could become a significant contributing factor.

We further, evaluated digitalisation in Czech healthcare based on a novel approach; we analysed emerging medical-related technologies (keywords) in research output

(publications, patents…) among Czech research institutions and firms. In the last decade (2009–2018), the most frequent new technologies (keywords) were those related to genetics (genomic, genetic sequencing), nanomaterials (nanoparticle and nanomedicine), e-health (data processing) and sensors necessary for IoMT. Moreover, 3D and laser are widespread in research output. While examining the trend, we found that among the most rapidly increasing technologies belong CRISPR, machine learning and energy storage. Whereas most of the publications and projects containing KWs related to the medical sector are naturally produced in faculties of medicine, hospitals, or institutes of the Czech Academy of Sciences, there were also several engineering faculties engaged. Patents in technological areas related to healthcare are to a large extent filed by companies, however, the Czech Academy of Sciences and universities are also listed in the top ten. An essential conclusion stemming from the KWs analysis is that to speed up the digitalisation of healthcare, a healthy innovation ecosystem across diverse industrial sectors is needed, such as medicine, electrical engineering, biology, and informatics.

According to the expert opinions of the selected sample respondents, the three principal transformative technologies trends for this decade and business opportunities for Czech companies are mainly: big data and their analysis, AI/machine learning for diagnosis assistance and chatbots, and IoMT/wearables, allow 24/7 monitoring. Other perspective technologies include cloud, augmented reality, shared medicine, genetics; and telemedicine. This overlaps with the findings of the most widespread/rapidly increasing emerging technologies in Czech scientific output (keywords) to a large extent.

The limitations of our paper and prospects for further research include more comprehensive research among firms and institutions involved in Czech healthcare, a more detailed analysis of research output with the focus not only on quantity but also on its quality, and a comparison to the situation in other countries.

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Notes

1 We looked at inventors rather than applicants since they are closer to the innovation activity. We included all patents with at least one Czech inventor. In addition, we distinguished between domestic and foreign/international patents, since patents filed abroad are more likely to have a higher value.

2 In many cases, there are more multiple entities cooperating on research outputs. We include entity mentioned as the first one.