Innovative approaches for health impact assessment in Europe: the role of digital tools and emerging devices

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Executive summary

The Report on innovative approaches for health impacts assessment in Europe: the role of digital tools and emerging devices, Deliverable 5.3 (D5.3), is prepared within Task 5.3 (T5.3) - Efficacy of new digital tools for covid-19 contact tracing and assessment of its impact on health and social behaviors of the project 'Population Health Information Research Infrastructure' (PHIRI). The purpose of the Report is to summarize the available information about innovative methods and digital tools addressing the covid-19 pandemic, as well as the effectiveness and impact of these new innovative tools in the European context.

Task 5.3 encompasses two subtasks:

i) 5.3.1 - Innovative methods for health monitoring in Europe: a cross-sectional study was conducted to identify which innovative methods, state-of-the-art algorithms and digital tools are being used in Europe to monitor covid-19 related health issues and their target populations. Legislative and ethical aspects regarding the use of digital tools were also considered;

ii) ii) 5.3.2 - Effectiveness and impact of tracking covid-19 patients: a systematic review of the literature was performed to determine the effectiveness and impact of tracking covid-19 patients using digitals tools, and to elucidate the potential role these new tools could have in future crises.

The findings of the two subtasks highlighted a higher level of implementation of digital tools during the pandemic to prevent the overload of national health systems and physical contacts, according to the public health measures in place. Several devices and online platforms were developed to inform, advice and support the general population regarding the main manifestations of the disease, preventive measures and contact centers. Most tools were used to guarantee the observance of quarantine measures and to track infected individuals in real-time. These digital devices were also deployed by health professionals for patients remote management, by epidemiologists for research activities, and by policy makers for evidence-based planning of public health interventions. The identified main barriers to the implementation of the new technology were data security and privacy issues related to most digital devices, misinformation and disinformation.

Key points

An appropriate regulatory and performance oversight, training of health providers in information and communication technologies, increasing population and media literacy will ensure major uptake of the tools, which will strengthen health systems preparedness for future health emergencies.

PHIRI: Report on innovative approaches for health impacts assessment in Europe: the role of digital tools and emerging devices

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I. Introduction

The PHIRI project aims to support research across Europe by facilitating the identification, access, and reuse of population health and non-health data according to FAIR Data principles (Findable, Accessible, Interoperable, and Reusable) [1] and Ethical, Legal and Social Implications (ELSI). To this end, the activities of T5.3 aimed at identifying which innovative methods, algorithms and digital tools (i.e., social media platforms, contact tracing devices, and artificial intelligence-based applications) are being used in Europe to monitor covid-19 and their main users. Legislative and ethical aspects inherent to the use of the applications were also taken into consideration with the aim to provide relevant recommendations that could facilitate the implementation of the tools while respecting the right to security and privacy of the end users.

II. Literature study

Most countries have developed various technological solutions or smart devices to monitor and contain covid-19. A wide range of digital tools have been developed worldwide and include national contact tracing applications (apps), online platforms against disinformation, dashboards, artificial intelligence-based apps, wearable devices, drones, etc. [2]. Asian countries were the first to develop and implement these solutions as the first covid-19 cases occurred in Asia. The first digital device was developed in Taiwan to enforce the quarantine [3]. In Singapore, citizens were obliged to install contact tracing apps into their mobile phones while tourist had to install another type of app and wear wristbands in order to monitor their compliance with the public health measures [4]. China also developed an app to monitor the citizens during the pandemic [5]. The digital tools proved effective in monitoring the spread of the coronavirus and became role models for the development and implementation of similar devices in Europe and beyond. Considering that the fundamental rights and freedoms of the citizens were not respected in some Asian countries [3,5], the European Commission (EC) issued recommendations to regulate the use of digital technologies in the European Union Member States (EU MS) during the pandemic. For instance, the EC recommended that data protection authorities should be involved in the development of the apps across Europe, a data controller responsible for the app's data processing should be nominated in each country, and download and installation of the apps should be on voluntary basis. However, legal and ethical issues still occurred across Europe, negatively impacting the deployment of the devices by the general population and healthcare providers. This prompt the necessity to identify and better understand the underlying causes limiting the diffusion of innovative solutions used to curb the covid-19 pandemic.

III. Aim

The objective of T5.3 is to identify which innovative technological solutions and algorithms are being used in Europe to monitor the covid-19 pandemic, who is using these devices, and legislative and ethical aspects related to the implementation of the new technologies. This study will enable the identification of issues in public health measures and gaps in the legislative system across Europe. The findings of the study will support evidence-based recommendations that could be applied in future health emergencies.

IV. Approach

The findings of the present Report stem from the research activities conducted in the following subtasks:

- 5.3.1: Innovative methods for health monitoring in Europe
- 5.3.2: Effectiveness and impact of tracking covid-19 patients

T5.3.1 Innovative methods for health monitoring in Europe

A cross-sectional study was performed to identify the digital solutions used in Europe to monitor and curb the pandemic, their target users and related legislative and ethical aspects. To this end, an ad hoc survey instrument (Appendix 1) was developed by the members of the research team at the Istituto Superiore di Sanità (ISS) and reviewed by the PHIRI coordination and colleagues from Robert Koch Institute (WP6). The final version of the questionnaire was administered through the National Nodes (WP4) to national representatives and partners of the PHIRI project. National Nodes are organisational entities bringing together national stakeholders in a country, such as national public health institute, national statistical office, and representatives from Ministries of Health and Research [6].

The national representatives received an invitation letter, including a consent to participate, with all necessary information regarding the PHIRI project, the coordinators and aims of the study. A link to the online survey was provided in the invitation letter if they consented to participate in the study. They were also asked to share the questionnaire with their colleagues involved in covid-19 surveillance and monitoring in their country, at regional or national level.

The questionnaire was composed of a section collecting socio-demographic data (name, country of origin, and email contact) and four sections with 27 questions collecting information about innovative tools:

- Innovative solutions implemented in the country. The questions were on digital methods used in monitoring the covid-19 pandemic; for research activities; to develop diagnostics and telehealth applications; to monitor COVID-19 vaccine uptake and curb misinformation or disinformation. For each digital device, information about guidelines, best practices, implementation level, target population, and impact assessment were required. The names and/or web links of existing platforms used to fight misinformation or disinformation were also required
- Algorithms (artificial intelligence). Information about algorithms to forecast the spread of the pandemic were collected, as well as the names and/or web links of available documents
- Legislative and ethical aspects. This section collected data on legislative and ethical aspects related to the implementation of the new devices in the participating countries; title and/or web links of available documents were required
- Comments. Additional information about digital tools were collected in this section.

Data about digital tools implemented in the countries of the study participants, including legislative and ethical aspects, were also retrieved from websites and documents provided by the respondents, and from the EC website [7].

The survey took place from December, 2021 to April, 2022 through Microsoft Forms. A descriptive analysis of the survey responses was performed using the statistical package SPSS v.28 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp).

T5.3.2: Effectiveness and impact of tracking covid-19 patients

A systematic review of the literature was conducted to assess the effectiveness and impact of tracking covid-19 patients using digitals tools, and to elucidate the potential role of these new tools in future health emergencies. The search was conducted on nine online databases; namely, the database of the World Health Organization (WHO), Pubmed, Biomed Central, Web of Science (WoS), Scopus, Cochrane Library, Chinese Center for Disease Control and Prevention (China CDC), the European Center for Disease Control and Prevention (ECDC), and Center for Disease Control and Prevention (CDC). A hand search was also performed to identify relevant articles from the reference list of systematic reviews.

Eligible studies for the systematic review were prospective and retrospective observational studies: case-control, cohort, cross-sectional, ecological studies and mathematical modeling studies. The detailed inclusion criteria are reported below:

- original research studies published from January, 2020 to October, 2021
- digital contact tracing of covid-19 in the population
- digital contact tracing relying on tracking systems, mostly mobile devices or web platforms
- population-based contact tracing (including nursing homes, long-term care facilities)
- modeling studies with real-world data or hypothetical populations
- studies providing quantitative data

The exclusion criteria were the following:

- not original research (review, commentary, editorial, conference papers, reports, viewpoint, etc.)
- off-topic: not covid-related, no digital contact tracing, etc.
- not published in English
- forecasting studies (modeling and forecasting the evolution of the covid-19 pandemic)
- hospital based contact tracing (only occupational exposure: among healthcare workers or between patients and healthcare workers)
- manual contact tracing only (reviewing reports/clinical charts, face-to-face interviews, phone contacts, etc.)

- studies providing only qualitative data

Data extraction of relevant information from the included studies was performed using an excel file, and distinguishing population-based studies (real world contact tracing) (Figure 1) from modeling studies (model simulations) (Figure 2).

<table>
<tr><th>1. GENERAL CHARACTERISTICS</th><th>2. APP UPTAKE BY THE POPULATION</th><th>4. EFFECTIVENESS OF DIGITAL CONTACT TRACING</th></tr>
<tr><td>First Author, year of publication</td><td>Persons who downloaded the app N(%)</td><td>Close contacts of COVID-19 cases identified N(%)</td></tr>
<tr><td>Country (study setting)</td><td>Total population that actively uses the app N(%)</td><td>Laboratory-confirmed COVID-19 cases detected from close contacts N(%)</td></tr>
<tr><td>Study design</td><td>All positive tests that occur among app users N(%)</td><td>Reduction of effective reproduction number (R_e or R_t) or reduction of covid-19 infections</td></tr>
<tr><td>Study period</td><td>3. SECURITY, ETHICAL AND PRIVACY CONSIDERATIONS</td><td>5. EXCLUDED ARTICLES</td></tr>
<tr><td>Study population</td><td>Privacy issues</td><td rowspan="6">Reasons for exclution</td></tr>
<tr><td>Name of the contact tracing device/electronic platform</td><td>Ethical issues</td></tr>
<tr><td>Type of device/platform</td><td rowspan="4">Security measures</td></tr>
<tr><td>Technology employed</td></tr>
<tr><td>Definition of “contact” used</td></tr>
<tr><td>Comparisons</td></tr>
</table>

Figure 1. Data extraction items for population-based studies

Country (study setting)	Type of model	Sample size/ number of simulations	Time horizon	Study population
Intervention	Comparison	Outcomes	Intervention effectiveness	Excluded articles

Figure 2. Data extraction items for modeling studies

The data extraction form included a brief glossary to define the types of study and related items, and terms related to the pandemic (Box 1). The definition of the studies were provided by the research team, while the definitions related to covid-19 (e.g., quarantine, isolation, etc.) were obtained from the CDC website (cdc.gov).

Box 1. Glossary of terms used in the data extraction form

- **Cross-sectional studies**: descriptive studies collecting data from a population at one specific point in time.
- **Cohort studies**: research participants are followed over a period of time (e.g., months, years)
- **Case-control studies**: studies comparing two groups of people: those with the disease or condition under study (cases) and a very similar group of people who do not have the disease or condition (controls)
- **Ecological studies**: descriptive studies that focus on the comparison of groups or populations, individual-level data are missing. Data are aggregated for analysis (es. time series)
- **Time horizon**: the time frame for the model simulation
- **Basic reproduction/reproductive number (R0)**: the average number of secondary cases produced by one infected individual introduced into a population of susceptible individuals. Also called basic reproductive ratio
- **Effective reproduction number (Re or Rt)**: the expected number of new infections caused by an infectious individual in a population where some individuals may no longer be susceptible. Estimates of Rt are used to assess how changes in policy, population immunity, and other factors have affected transmission at specific points in time
- **Close contact**: someone who was less than 6 feet away from an infected person (laboratory-confirmed or a clinical diagnosis) for a cumulative total of 15 minutes or more over a 24-hour period (cdc.gov)
- **Quarantine**: a strategy used to prevent transmission of COVID-19 by keeping people who have been in close contact with someone with COVID-19 apart from others (cdc.gov)
- **Isolation**: used to separate people with confirmed or suspected COVID-19 from those without COVID-19 (cdc.gov)

Quality assessment of the included records was performed with validated instruments. The Effective Public Health Practice Project tool (EPHPP) was used for the evaluation of population-based studies

[8], while modeling studies were evaluated with an adapted version of the Consolidated Health Economic Evaluation Reporting Standards checklist (CHEER) [9]. Some questions were omitted from the CHEERS checklist (i.e., 1, 6, 8-14, and 19-21) as they were not relevant to non-economic modeling studies. Given the heterogeneity of the included studies, a qualitative synthesis of the findings was provided.

V. Results

T5.3.1 Innovative methods for health monitoring in Europe

A total of 19 national representatives from 14 countries participated in the study with one participant in each country, except Croatia, Finland, Germany, Ireland, Italy and Spain that had two respondents each (Table 1). The respondents from these six countries were in agreement in most cases; when disagreements occurred, the response of the representative providing documents or links to websites was taken into consideration.

1. Covid-19 monitoring tools

Several digital tools (Table 1) are used to monitor the covid-19 pandemic in all countries, an exception is Serbia. The tools are used for contact tracing of infected individuals, covid-19 symptoms checking, booking for covid-19 testing and other general health functionalities. The tools are deployed by the general population, healthcare professionals, and researchers. The tools were mostly downloaded in Germany, Finland and in the United Kingdom (UK) by at least 50% of the population and were actively used in the Netherlands, where all 25 Dutch regional health services adopted the tool Clusterbuster, in Ireland (35% of the population) and Finland (30% of the population).

The covid-19 monitoring app of the Republic of Slovakia was available for a few months in 2020 and then withdrawn by the Slovak National Health Information Centre for privacy and security reasons. However, the app was downloaded by almost 2% of the population before being deactivated.

Table 1. Digital tools used for covid-19 monitoring in Europe

COUNTRY	DIGITAL TOOL	FUNCTION	TARGET population	UPTAKE RATE (as of April 2022)		WEBSITE
				% active users	Downloads (% of population)	
Austria	STOPP CORONA	contact tracing; health functionalities	general population	—	1,4 million (16%, Feb 2021)	https://www.roteskreuz.at/site/meet-the-stopp-corona-app/
Croatia	Stop COVID-19	contact tracing	general population	—	236,553 (6%)	https://www.koronavirus.hr/stop-covid-19/723
Finland	Koronavilkku (CoronaBlinker)	contact tracing	general population	—	2,75 million (50%)	https://koronavilkku.fi/en/
	OMAOLO	COVID-19 symptoms checking	general population	1,72 million (30%, Jan 2021)	na	https://www.omaolo.fi/
Germany	Corona-Warn-App	contact tracing	general population, health care providers	—	over 47 million (57%)	https://www.coronawarn.app/en/; https://www.coronawarn.app/en/analysis/
Ireland	COVID Tracker	contact tracing; COVID-19 symptoms checking	general population	1,7 million (35%)	—	https://www2.hse.ie/services/covid-tracker-app/why-use-the-covid-tracker-app.html
Italy	IMMUNI	contact tracing	general population	—	21,8 million (37%)	https://www.immuni.italia.it/
Lithuania	Korona STOP LT	contact tracing; health functionalities	general population	—	350,000 (12.5%)	https://koronastop.lrv.lt/en/
Netherlands	CoronaMelder	contact tracing	general population	over 2 million (12%)	—	https://coronamelder.nl/en/
	Clusterbuster	regional COVID-19 surveillance (clusters, outbreaks, vaccination rate)	public health physicians/ epidemiologists working within the 25 Dutch regional health services	100%	na	https://www.rivm.nl/regionale-infectieziektebestrijding/clusterbuster-regionale-surveillance-applicatie-covid-19; https://www.rstudio.com/blog/how-the-clusterbuster-shiny-app-helps-battle-covid-19-in-the-netherlands/

Portugal	Stayaway COVID App	contact tracing	general population, primary care physicians, chronic patients	—	2.9 million (25%, Jan 2021)	https://stayawaycovid.pt/en/
Serbia	No monitoring app	na	na	na	na	na
Slovakia	Zostan Zdravy (Stay Healthy)	contact tracing; testing	general population, health care providers, epidemiologists	—	over 90,000 (2%, April 2020)	https://github.com/ct-report/SK
Slovenia	OstaniZdrav (Stay Healthy)	contact tracing	general population	—	over 460,000 (22%)	https://www.gov.si/en/topics/coronavirus-disease-covid-19/the-ostanizdrav-mobile-application/
Spain	Radar COVID	contact tracing; health functionalities	general population	—	—	https://radarcovid.gob.es/en/terms-and-conditions-use; https://radarcovid.gob.es/recursos-de-comunicacion
United Kingdom	NHS COVID-19 app	contact tracing; COVID-19 symptoms checking, testing	general population	—	29,5 million (50%)	https://covid19.nhs.uk/

na, not applicable; ---, no data; NHS, National Health Service

A decentralized contact tracing system was in place in 11 countries (Table 2), while a centralized contact tracing system was used in two countries (Lithuania, Slovakia). Data exchange between the devices relied on Bluetooth for all apps. The Slovakian app used the Global Positioning System (GPS) for geolocalization.

The effectiveness of digital contact tracing devices was evaluated through impact assessments performed directly by national health institutes, expert groups or private companies nominated by the government (Croatia, Finland, Germany, Italy, the Netherlands, Portugal, Spain, and the UK). The evaluations included pilot studies, analysis of covid-19 data, comments from the end-users, population-based surveys, and technical reports. Contact tracing apps have been discontinued, as of September 2022, in Austria, Finland, Ireland, the Netherlands, Portugal, and the Republic of Slovakia. Guidelines, reports or best practices on digital monitoring tools are available on the websites of each tool. In some cases, the documents are available only in national languages (Austria, Germany, the Netherlands, Slovenia, Spain) or the related websites are not accessible by external users (Portugal).

Table 2. Technical characteristics of covid-19 monitoring tools

COUNTRY	DIGITAL TOOL	CENTRALIZED or DECENTRALIZED SERVER	COMMUNICATION TECHNOLOGY	IMPACT ASSESSMENT	STATUS (as of September 2022)
Austria	STOPP CORONA	decentralized	Bluetooth	No	Discontinued from February 28, 2022
Croatia	Stop COVID-19	decentralized	Bluetooth	End-users	Active
Finland	Koronavilkku (CoronaBlinker)	decentralized	Bluetooth	No	Discontinued
	OMAOLO	decentralized	web-based	Survey	Active
Germany	Corona-Warn-App	decentralized	Bluetooth	App analytics, survey	Active
Ireland	COVID Tracker	decentralized	Bluetooth	No	Discontinued for contact tracing
Italy	IMMUNI	decentralized	Bluetooth	Surveys, reviews, expert group	Active
Lithuania	Korona STOP LT	centralized	Bluetooth	No	Active
Netherlands	CoronaMelder	decentralized	Bluetooth	Expert group	Temporarily suspended from April 22, 2022
	Clusterbuster	—	—	End-users	Active
Portugal	Stayaway COVID App	decentralized	Bluetooth	Expert group	Discontinued
Serbia	No app	na	na	na	na
Slovakia	ZostanZdravy (Stay Healthy)	centralized	Bluetooth, GPS	No	Discontinued
Slovenia	OstaniZdrav (Stay Healthy)	decentralized	Bluetooth	No	Active
Spain	Radar COVID	decentralized	Bluetooth	Pilot study	Active
United Kingdom	NHS COVID-19 app	decentralized	Bluetooth	Surveys	Active

na, not applicable; --, no data; NHS, National Health Service; GPS, Global Positioning System

2. Tools used for research purposes, diagnostics and telehealth

According to the respondents, all participating countries have developed digital tools used in research activities, for diagnostics and telehealth applications (Table 3). The tools were used for patient remote visits and monitoring, referrals, and consultations with other medical specialists. Health data collected with tools were also used for research purposes. The main users of these tools were the general population, healthcare professionals, and patients.

The uptake rate varies across Europe; it was mostly low/medium except in Finland, Portugal, the Republic of Slovakia and Slovenia with high uptake rates. Impact assessments of the new devices were performed by authorized agencies or institutes, as reported for Ireland, Italy, Portugal, and Spain. Although guidelines and technical documentations concerning the digital applications are available in most countries, they are not always publicly accessible (Republic of Slovakia) or are available only in the national language (Spain). The respondents did not provide information for Austria, Germany, the Netherlands and the UK.

Table 3. Digital applications used in diagnostics, telehealth and research

COUNTRY	DIGITAL TOOL	UPTAKE RATE	IMPACT ASSESSMENT	GUIDELINES, REPORTS, BEST PRACTICES
Austria	—	—	—	—
Croatia	Telemedicine (teleradiology)	Low	No	Yes
Finland	Telemedicine, digital health devices	High	Yes	Yes
Germany	—	—	—	—
Ireland	Telemedicine	—	Yes (HSE National Telehealth Steering Committee)	Yes
Italy	Telemedicine, digital health devices	Low/medium	Yes (Italian Digital Health Observatory)	Yes
Lithuania	Telemedicine	Low/medium	—	—
Netherlands	—	—	—	—
Portugal	Telemedicine	High	Yes (system analytics)	Yes
Serbia	Telemedicine	Low	—	—
Slovakia	Digital health devices	High	No	Yes
Slovenia	Central Patient Data Register, Telemedicine, online conference platforms	High (Central Patient Data Register)	No	Yes
Spain	Telemedicine, digital health devices	Low/medium	Yes (Spanish Agency on HTA)	Yes
United Kingdom	—	—	—	—

HSE, Health Service Executive; HTA, Health Technology Assessment; ---, no data

3. Covid-19 vaccination coverage

Digital platforms or dashboards are publicly accessible and can be used to monitor covid-19 vaccination uptake and issue covid-19 certificates (Table 4); exceptions are Portugal and Serbia. The platforms provide timely data about vaccination coverage by region, type of vaccine, number of doses delivered and administered, and age groups.

Electronic vaccination registries are also available and can be accessed by health services providers and registered citizens in the Netherlands and Slovenia. The BIFAP is a database of primary care medical records used in Spain to collect clinical data from vaccinated subjects. The database serves as the principal source of data for health professionals and epidemiologists conducting pharmaco-epidemiological studies. A vaccination register is also available in Italy to collect vaccination data from all regions and autonomous provinces. Access to the register was granted to Italian national institutes during the emergency [10]. Information about the electronic databases were available only in the national languages of Finland, Lithuania and Slovenia.

Table 4. Digital devices for covid-19 vaccination monitoring in Europe

COUNTRY	COVID-19 VACCINATION DATA	WEBSITE
Austria	online platform	https://info.gesundheitsministerium.at/
Croatia	online platform	https://www.koronavirus.hr/en
Finland	online platform	https://www.thl.fi/episeuranta/rokotukset/koronarokotusten_edistyminen.html
Germany	online platform	https://impfdashboard.de/en/
Ireland	online platform	https://covid19ireland-geohive.hub.arcgis.com/
Italy	online platform	https://www.governo.it/it/cscovid19/report-vaccini/
Lithuania	online platform	https://osp.stat.gov.lt/praejusios-paros-covid-19-statistika
Netherlands	vaccination registry	https://www.rivm.nl/en/covid-19-vaccination/privacy
	online platform	https://coronadashboard.government.nl/landelijk/vaccinaties
Portugal	—	—
Serbia	—	—
Slovakia	online platform	www.korona.gov.sk; https://covid-19.nczisk.sk/en
Slovenia	eRCO – Electronic Registry on Immunizations and Adverse Events	https://www.nijz.si/sl/elektronski-register-cepljenih-oseb-in-nezelenih-ucinkov-po-cepljenju-erco
Spain	BIFAP database	https://www.aemps.gob.es/informa/el-programa-bifap-en-la-vigilancia-de-la-seguridad-de-las-vacunas-frente-a-la-covid-19/?lang=en
United Kingdom	online platform	https://coronavirus.data.gov.uk/details/vaccinations

BIFAP, pharmaco-epidemiological research database for public health systems; ---, no data

4. Online platforms against misinformation and disinformation

Websites against disinformation (fake news) and/or misinformation (misleading information) about covid-19 or screening for products with alleged healing or protective effects were reported for 11 countries in the study (Table 5). These websites are the official websites of Ministries of Health (Italy, Portugal), National Institutes of Public Health (Croatia, Italy, the Netherlands, Slovenia), health services providers (Ireland), and websites supported by the government (Germany, Slovakia, the UK) and national associations (Austria, Italy). Fake and misleading information during the pandemic were also tackled through social media (e.g., TikTok, Twitter, Facebook, Instagram) and search engines (e.g., Google).

Table 5. Online platforms fighting misinformation and disinformation

COUNTRY	PLATFORMS AGAINST DIS- or MISINFORMATION	NAME of the platforms	WEBSITE
Austria	yes	Austrian Health Literacy Alliance	https://oepgk.at/fake-news/ https://oepgk.at/english-summary/
Croatia	yes	Croatian Institute of Public Health	https://www.hzjz.hr
Finland	—	—	—
Germany	yes	Facts for Friends	https://factsforfriends.de/about-us
Ireland	yes	HSE through Facebook, Instagram	—
Italy	yes	VaccinarSi	https://www.vaccinarsi.org/;
		Ministry of Health	https://www.salute.gov.it/portale/nuovocoronavirus/archivioFakeNewsNuovoCoronavirus.jsp
		National Institute of Health	https://www.iss.it/en/primo-piano/-/asset_publisher/3f4alMwzN1Z7/content/covid-dall-iss-un-vademecum-contro-le-fake-news-sui-vaccini
		Facebook	https://it-it.facebook.com/formedia/tools/coronavirus-resources
Lithuania	—	—	—
Netherlands	yes	RIVM controls information on social media	https://www.rivm.nl/en
Portugal	yes	Ministry of Health	https://covid19.min-saude.pt/
Serbia	—	—	—
Slovakia	yes	Government website: Coronavirus (covid-19) in the Slovak Republic	www.korona.gov.sk

Slovenia	yes	National Institute of Public Health through its social media accounts (Facebook, TikTok, Instagram, Twitter)	https://www.facebook.com/nijz.si; https://www.tiktok.com/@_nijz; https://www.instagram.com/_nijz_/; https://twitter.com/NIJZ_pr
Spain	yes	Cepimose (Let's vaccinate)	www.cepimose.si
		Maldita	https://maldita.es/
		2020 Law against disinformation	https://www.boe.es/eli/es/o/2020/10/30/pcm1030
United Kingdom	yes	UK Government through Facebook, Twitter, TikTok, Google, Apple News	https://www.ofcom.org.uk/research-and-data/media-literacy-research/coronavirus-resources

HSE, Health Service Executive; RIVM, National Institute for Public Health and the Environment; ---, no data

5. Artificial intelligence used to predict the spread of the coronavirus

The respondents from Germany, Italy, Spain, and the UK provided examples of algorithms used to forecast the spread of the coronavirus in their countries. In Germany, the Corona-Datenspende predicts SARS-CoV-2 infections using data from wearables devices with inbuilt sensors (e.g., accelerometers, temperature and optical sensors). The collected health data from the sensors are sent as anonymized data to a server where data are combined and analysed to create a Fever Map. The Map can detect geographic areas in which the number of subjects with fever symptoms is higher than the average [11]. Moreover, the project Control and prognosis of intensive care COVID-19 capacities (SPoCK) is used to predict the expected number of covid-19 patients requiring intensive care in Germany. Covid-19 prevalence and incidence rates of infections and the capacities of intensive care units are used in the forecasting models [12]. In Italy, within the project Exscalate4CoV, the biological agents targeting the coronavirus will be identified and an effective tool to contain future pandemics is under development [13]. In Spain, artificial intelligence devices are used to identify covid-19 clusters [14], predict excess mortality or all-cause mortality due to surface temperature [15], and to identify the main factors influencing the spread of coronavirus [16]. In the UK, the QCovid is used to detect patients at high risk of severe covid-19 outcomes, and two new risk prediction algorithms have been validated to estimate the risk of covid-19 mortality and hospital admission in vaccinated subjects [17].

6. Other digital solutions used during the covid-19 pandemic

A digital assistant called ‘Andrija’ using artificial intelligence has been developed in Croatia to assist the citizens in diagnosing and managing of COVID-19 infections; it also connects citizens with health authorities for further support. Digital apps used to verify and save covid-19 certificates are available in most countries (e.g., Croatia, Lithuania, Ireland, Italy). Several websites have been developed or adapted to support victims of domestic violence (Croatia, Germany), for financial aid (Germany), and for remote teaching (e.g., Teams, YouTube, Zoom) during covid-19 lockdowns.

7. Legislative and ethical considerations

Specific legal measures have been introduced worldwide to support covid-19 monitoring and curb the pandemic using new technological solutions, as well as to facilitate timely data collection and sharing. The EC issued recommendations to regulate the use of digital applications and health data for predicting the spread of the infection [18]. The European Data Protection Board issued guidelines for the use of location data and contact tracing tools during the pandemic [19]. The guidelines and recommendations were adopted by the Member States, where data protection authorities supervised the development and implementation of the devices. This was not the case in Slovenia, where the national data protection authority was not involved in the development of the monitoring app and a data controller was not individuated by the Slovenian government [20]. Another example is the Republic of Slovakia where the law ‘Lex Corona’ that permits contact tracing based on data from mobile devices was approved by the government. The Slovak Constitutional Court suspended the effect of the law due to privacy and security issues. Consequently, the app Zostan Zdravy was discontinued, depriving the citizens of a monitoring tool [20].

Member States also adopted the WHO recommendations concerning certification of death during the pandemic (e.g., Italy, Spain), guaranteeing high and comparable quality of information in medical death certificate [21].

T5.3.2: Effectiveness and impact of tracking covid-19 patients

A total of 8,743 records were identified from nine online databases and a hand search (Figure 3). After removing duplicates, over 7000 records were screened by title and abstract, leaving 58 full text articles to be assessed for eligibility. Finally, 37 articles (13 population-based and 24 modeling studies) were included in the qualitative synthesis.

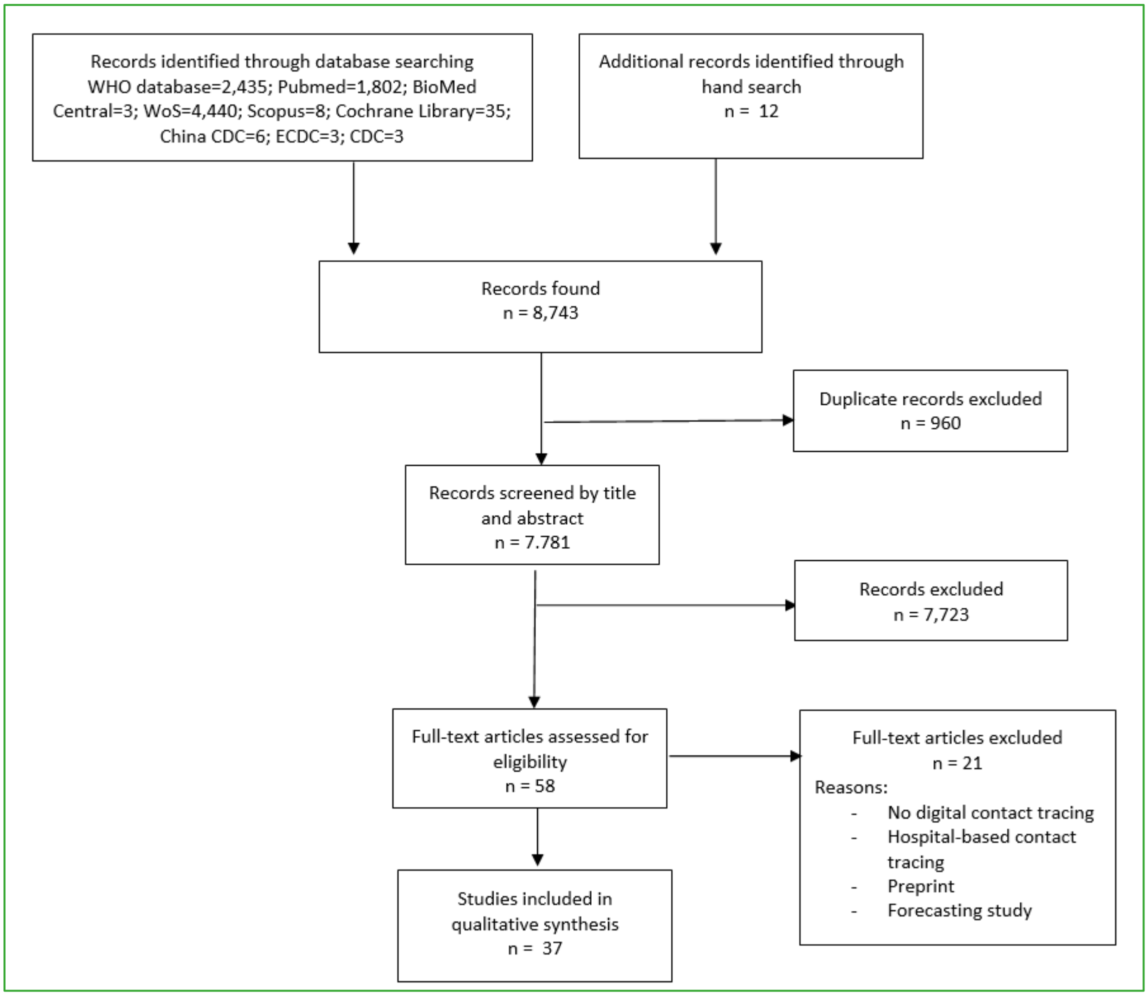

Figure 3. Flow diagram of the selection of records on covid-19 contact tracing

1. Population-based studies

The main characteristics of the 13 population-based studies are reported in Table 6. The majority (10/13 studies) was published in 2020 [22-31] and in Asian countries (6/13) [22,24,25,27,30,31]. A multinational study was conducted in Asian and European countries [29]. Most studies (9/13) were observational (cross-sectional) [22-26,28,30-32]; of these, two studies had also a cohort design [28,30]. The study population was the general population in all studies, except in the study by Mack 2021 [32] in which National Football League (NFL) players and staff members were the target groups.

The devices evaluated in the studies were mostly mobile phones, with or without other tracking systems (10/13) [22-25,27-30,33,34]. Wearable devices [32] and web-based monitoring tools [26] were examined in one study each, while Zhang et al., 2020 considered different electronic monitoring systems [31]. The technology employed for geolocalization or geotracking was a combination of mobile phones operating systems (Android and Apple), closed-circuit television (CCTV), electronic payment history and text messaging systems. Data exchange among devices was based on GPS and Bluetooth technologies. Manual contact tracing was also deployed in seven studies [22-24,26,30-32].

Table 6. Characteristics of population-based studies

First author, year of publication	Country	Study design	Study population	Name of the contact tracing device	Type of device/platform	Technology employed
Bae, 2020	Korea	Cross-sectional	General population	nr	Smartphone	Manual contact tracing + GPS of mobile phones + credit card transactions + CCTV
Barrett, 2020	Ireland	Cross-sectional	General population	Automated text messaging system	Mobile telephone + text broadcasting software	Text message-based system
Chen, 2020	Taiwan	Cross-sectional	General population	Multiple systems used	Smartphone + CCTV + credit card terminals + geotracking system	Manual contact tracing + GPS + credit card transactions + CCTV + mobile geotracking system
Fetzer T, 2021	UK (England)	Ecological, natural experiment	General population	NHS COVID-19 app	Smartphone	Google Apple EN system + Android and iOS operating systems + Bluetooth
Jian, 2020	Taiwan	Cross-sectional	General population	TRACE (national contact tracing platform)	Smartphone-based system + web-app	Manual contact tracing + GPS + web-app contact management system
Krueger, 2020	USA	Cross-sectional	General population	Sara Alert (symptom monitoring system)	Web-based symptom monitoring tool	Manual contact tracing + automated monitoring via web-based symptom monitoring tool
Kwon, 2020	Korea	Experimental study (cohort)	General population	Epidemic Investigation Support System (EISS)	Smartphone + CCTV + credit card terminals	Mobile geotracking system + credit card transactions + CCTV
Mack, 2021	USA	Cross-sectional	NFL players and staff members	KINEXON	Wearable proximity device	Proximity device + manual contact tracing
Salathé, 2020	Switzerland	Cross-sectional, cohort	General population	SwissCovid app	Smartphone + FOPH computer server	EN framework via Bluetooth
Urbaczewski, 2020	China, Germany, Italy, Singapore, South Korea, USA	Ecological	General population	nr	Smartphone	GPS, Bluetooth

Wymant, 2021	UK (England and Wales)	Ecological	General population	NHS COVID-19 app	Smartphone	Google Apple EN system + Android and iOS operating systems + Bluetooth
Yamamoto, 2020	Japan	Cross-sectional, cohort	General population	K-note (PHR-based health observation app)	Smartphone or tablet app integrated with PHR-based app	Manual contact tracing + digital symptom monitoring tool + email + manual data visualization by Excel macro
Zhang, 2020	China	Cross-sectional	General population	na	Geolocalization (geotracking) system + different electronic systems	Manual contact tracing + mobile phone location data + big data technology + electronic payment history

CCTV, closed-circuit television; FOPH, Swiss Federal Office of Public Health; PHR, Personal Health Record; NHS, National Health Service; GPS, Global Positioning System; iOS: iPhone Operating System; NFL, National Football League; EN, Exposure Notification

The uptake rates of the devices, in terms of download and percentage of active users, were not referred to the entire population but to the sample size of the study and were also reported differently in each study (e.g., percentage of enrolees that accepted to download and use the app, increment of the percentage of users during the study, number or percentage of notified cases). The number of positive test identified among active users ranged across the studies from 3 [27] to over 889,000 [29].

Information about privacy issues (e.g., privacy from authorities, privacy from contacts, user consent and use of the app on voluntary basis), ethical issues (e.g., equity, harms from false positive/negative results), and security measures (e.g., cyber attack protection through passwords, anonymization techniques, centralized or decentralized server system) were extracted from the included studies. They underlined the possibility of data security issues and privacy breaches related to the use of the devices. The use of monitoring apps was compulsory in South Korea, Singapore [22, 29] and Taiwan [24]. According to the Taiwan Infectious Disease Control Act, which was mandated after the outbreak of the Sever Acute Respiratory Syndrome (SARS) in 2007, authorization or consent to the retrieval of individual information related to the outbreak of disease under the auspice of the government can be waived in case of emerging infectious diseases, such as SARS-COV-2 [24]. In South Korea, covid-19 related data were collected as part of an epidemiological investigation of the Korean Centers for Disease Control and Prevention (KCDC), and individual consent was not applicable; the use of the data was approved by the KCDC [22]. A centralized server system for the storage and processing of the collected data was in place in Italy, Singapore, USA, China [29], Taiwan [25], and in the UK [34]. Decentralized systems were implemented in Switzerland [28], Japan [30] and in some States in the USA [23,27,29, 31,33], while ethical issues were not considered in 11/13 studies [23,25-34]; privacy considerations were lacking in four studies [27,31,32,34].

To assess the effectiveness of digital contact tracing (Table 7), the following information was taken into consideration:

a) Close contacts of covid-19 cases identified and number of close contacts per index case. The number of close contacts identified ranged across the studies from 5 [31] to 1.7 million [33], and from 0.24 close contacts per index case [28] to 16.5 [25];
b) Laboratory-confirmed covid-19 cases detected from close contacts. This value ranged from zero [24] to 66.8% confirmed cases [26];
c) Reduction of effective reproduction number (Re or Rt) or reduction of covid-19 infections. One study reported the Rt, which was above 6 at the beginning of the outbreak and was lower than 1 after the lunch of the epidemiological investigation [22]. A substantial reduction of covid-19 infections was reported in three studies [32-34].

The included population-based studies suggested that digital contact tracing with mobile position data followed by self-quarantine and isolation may be a useful means of preventing the spread of covid-19 through early identification of symptomatic and positive covid-19 cases. However, digital monitoring and surveillance require robust information technology infrastructure, a high level of implementation of the devices in the population, sufficient laboratory capacity and dedicated clinical and administrative support. The findings also suggested that the contact tracing period, thus prevention of transmission opportunities, should be before the onset of symptoms.

Table 7. Effectiveness of digital contact tracing

First author, year of publication	Close contacts of covid-19 cases identified; number of close contacts per index case	Laboratory-confirmed covid-19 cases detected from close contacts	Reduction of effective reproduction number (R_e or R_t) or reduction of covid-19 infections
Bae, 2020	1,687 (14,5 ±26,3 close contacts per index case)	108 (6,4%)	Rt = 6,1 at the beginning of the outbreak; Rt<1 two days after the epidemiological investigation was launched. Reproduction number of the present outbreak was 0,79 (95%CI 0,66-0,93)
Barrett, 2020	1,336	35 (2.6%)	nr

Chen, 2020	627,386 possible contact-persons were identified.	None of the symptomatic or hospitalized contacts were confirmed as cases	nr
Fetzer, 2021	nr	nr	Cases subject to proper contact tracing were associated with a reduction in subsequent new infections of 63% and a reduction in subsequent COVID-19–related deaths of 66%
Jian, 2020	8,051 close contacts (16.5 close contact/case; 95%CI 13.9-19.1)	of 8,051 close contacts, 147(1.8%) were confirmed to have covid-19	nr
Krueger, 2020	1,622 contacts; 2.9 per index case (95%CI 0-31)	of 190 close contacts, 127 (66.8%) were confirmed to have covid-19	nr
Kwon, 2020	13	2 (15,4%; 95%CI 8,3%-22,5%)	na
Mack, 2021	189	20 (11%)	COVID-19 transmission was reduced through environmental change, increased personal protection, avoidance of high-risk interactions
Salathé, 2020	185 exposed contacts (cohort study); 0.24 (95%CI 0.20-0.27) per index case	nr	nr
Urbaczewski, 2020	nr	nr	nr
Wymant, 2021	1.7 million (4.2 per index case)	6% of 1.7 million notifications (CI 5.96–6.09%)	On average, each confirmed covid-19 positive individual who consented to notification of their contacts through the app prevented one new case.
Yamamoto, 2020	cohort: 72; cross-sectional: nr	nr	na
Zhang, 2020	5 out of 100 secondary cases (5%)	nr	nr

nr, not reported; na, not applicable

The quality assessment of population-based studies, performed with the EPHPP tool [8], is depicted in Table 8. The majority of the studies (9/13) achieved a moderate quality level (with one weak section rating). A strong global rating was obtained by two studies [28,29], as they had no weak ratings in any section. Weak global ratings (two or more weak section ratings) were also achieved by two articles [25,26], due to the study design and blinding sections. The sections ‘confounders’ and ‘withdrawals and dropouts’ were not applicable in all studies.

Table 8. Global ratings of the population-based studies

First author, year	SELECTION BIAS	STUDY DESIGN	CONFOUNDERS	BLINDING	DATA COLLECTION METHODS	WITHDRAWALS AND DROP-OUTS	GLOBAL RATING of the paper
Bae, 2020	moderate	weak	na	moderate	strong	na	moderate
Barrett, 2020	moderate	weak	na	moderate	strong	na	moderate
Chen, 2020	moderate	weak	na	moderate	strong	na	moderate
Fetzer, 2021	moderate	weak	na	moderate	strong	na	moderate
Jian, 2020	moderate	weak	na	weak	strong	na	weak
Krueger, 2020	strong	weak	na	weak	strong	na	weak
Kwon, 2020	moderate	weak	na	moderate	strong	na	moderate
Mack, 2021	moderate	moderate	na	weak	strong	na	moderate
Salathé, 2020	moderate	moderate	na	moderate	strong	na	strong
Urbaczewski, 2020	moderate	moderate	na	moderate	strong	na	strong
Wymant, 2021	moderate	weak	na	moderate	strong	na	moderate
Yamamoto, 2020	moderate	weak	na	moderate	strong	na	moderate
Zhang, 2020	moderate	weak	na	moderate	strong	na	moderate

2. Model-based studies

A total of 24 modeling studies were included in the systematic review, their main characteristics are presented in Table 9.

Table 9. General characteristics of modeling studies

First author, year of publication	Country (study setting)	Type of model	Sample size/ number of simulations	Study population
Abueg, 2021	USA (Washington State)	Agent-based models	representative synthetic populations of three counties	General population
Barrat, 2020	France, Denmark	Compartmental model	10,000 simulations of each scenario	Students and workers
Currie, 2020	Australia	Dynamic aggregate-level model (modified SEIR model)	26 million	General population
Nakamoto, 2020	Japan	Compartmental model (SIR)	15 million	General population
Whaiduzzama, 2020	Australia	Integrated PPMF	nr	Hypothetical population

Yasaka, 2020	nr	Transmission graph (adapted SIR model)	10 random simulations per adoption rate (0%, 25%, 50%, 75%)	Hypothetical population
Moreno Lopez, 2021	France	Agent-based model	nr	Synthetic population (based on INSEE censuses)
Pollmann, 2021	nr	Two types of deterministic models; two individual-based models with the MC simulation technique,	over 10,000 simulated scenarios	Hypothetical population
Bradshaw, 2021	nr	Stochastic branching-process model	nr	Hypothetical population
Almagor, 2020	UK	Agent-based model	103,000 agents with 140 simulated scenarios; each simulation repeated 20 times	Synthetic population derived from the 2011 UK Census
Kucharski, 2020	UK	Transmission model	40,162 UK participants; 25,000 individual-level transmission between a primary case and their contacts were simulated	General population
Ferrari, 2021	Italy	Compartmental model (SIR)	12 scenarios were simulated with varying contact rate and proportion of app users (0, 0.25, 0.5, and 0.75); 5500 simulations per scenario.	Population from 110 Italian districts updated to 2016.
Wilmink, 2020	USA	Compartmental model (SEIR)	hypothetical population of 120 persons (80 residents and 40 staff)	Hypothetical population
Wallentin, 2020	Austria	Agent-based model	Four scenarios simulated 6 times each	General population (Salzburg)
Ferretti, 2020	nr	General mathematical model	40 source-recipient pairs	Hypothetical population
Bulchandani, 2021	nr	Branching-process model	Model simulated on 10,000 nodes with 100 initial infections	Hypothetical population
Nuzzo, 2020	USA	Compartmental model (SEIR)	nr	Hypothetical population
Kim, 2021	nr	nr	nr	Hypothetical population
Hinch, 2020	UK	Individual based model	1 million	General population

Firth, 2020	UK	Epidemic network-based model	468 individuals	General population
Peak, 2020	nr	Stochastic branching model	nr	general population
Aleta, 2020	USA	Agent-based model	85,000 agents (64,000 adults, 21,000 children)	Syntetic popoulation of the Boston metropolitan area
Kretzschmar, 2020	Netherlands	Stohastic mathematical model	1000 individuals for all scenarios	General population
Bicher, 2021	Austria	Agent-based model	about 9 million for Austria	General population

nr, not reported; SEIR, Susceptible-Exposed-Infectious-Removed; SIR, Susceptible-Infected-Removed; MC, Monte Carlo; PPMF, mobile-fog computing framework

Most studies (16/24) were conducted in 2020 [35-50] and in Europe (8/24) [35,40,41,43,46,47,50-52,58]; the country or setting was not specified in seven studies [39, 44,48,53-56]. Various models were used in the studies, including compartmental models such as Susceptible-Infected-Removed (SIR) and Susceptible-Exposed-Infectious-Removed (SEIR); SIR and SEIR adapted versions, agent-based models, individual-based models, etc. The general population was the study target in 11/24 studies [36, 37,40,43, 46-48,50,52,57,58], followed by hypothetical populations in 9 studies [38,39,42,44,45,53-56]. The sample size of the studies varied greatly and reached 26 million [36]; likewise for the number of simulations that ranged from 6 [43] to over 10,000 [56].

The interventions considered in the studies (Table 10) were mostly a combination of strategies including digital contact tracing, manual contact tracing, and non-pharmaceutical interventions (e.g., social distancing, generalized lockdowns, hand hygiene, mask wearing). Recursive contact tracing (not only tracing direct contacts but also contacts of contacts, etc.) [56] and bidirectional contact tracing were also considered in the models and proved to be more effective than forward-tracing alone. Bidirectional contact tracing deploys ‘reverse-tracing’ to identify the ‘parent case’ who infected a known case, then continues tracing to discover other cases related to the parent case [55].

Digital exposure notifications alone are unlikely to control the covid-19 pandemic. The overall effect of digital exposure notifications depends on various factors, including the fraction of the population that adopts the digital device and the delay between infection and exposure notification [55]. The adoption rate of digital devices is the main factor impacting the spread of an outbreak. When the uptake rate for contact tracing apps increases, the effective reproduction number decreases gradually. To contain the spread of covid-19 (i.e., Rt<1), about 90% participation of the population would be required [37].

However, a contact tracing app can be effective without 100% participation; infact even a 25% adoption would provide some suppression of the infection curve compared to no adoption. The use of geotracking technologies (e.g., GPS) may enable a better estimation of the user real-time location at points of contact, but it presents privacy concerns [39].

To achieve better outbreak control, digital contact tracing should be combined with other measures, such as mask wearing, social distancing, and/or covid-19 testing. The availability of fast testing, and coordination of test results with digital contact tracing, are important for symptomatic cases to become index cases for tracing, and to release healthy contacts from quarantine [56]. Digital contact tracing causes a large fraction of the healthy population to be traced and quarantined. In general, the higher the level of exposure notification adoption the greater the number of total quarantine events [57]. The benefits of combining digital contact tracing with additional containment measures are higher reduction of epidemic size and lower societal cost, in terms of quarantines [35].

Table 10. Interventions considered in modeling studies

First author, year	Intervention
Abueg, 2021	Exposure notifications, non-pharmaceutical interventions
Barrat, 2020	isolation, manual contact tracing, DTC, recursive contact tracing
Currie, 2020	3 testing scenarios: 1) maintaining testing at May 2020 levels until December 2020 (no tapering), 2) testing levels tapering by 5% per month, and 3) testing levels tapering by 10% per month AND 2 social distancing scenarios: 1) with a more rapid reduction; 2) with a slower reduction maintained over time
Nakamoto, 2020	Scenarios (households, schools, workplaces, etc.) in which the epidemic is established and countermeasures such as contact tracing are employed to control the spread of COVID-19
Whaiduzzaman, 2020	DTC
Yasaka, 2020	DTC, quarantine
Moreno Lopez, 2021	combined impact of DCT + testing and isolation of clinical cases and household members
Pollmann, 2021	DCT, quarantine, testing, social distancing
Bradshaw, 2021	DCT with/without manual tracing, isolation
Almagor, 2020	DTC, testing, self-isolation
Kucharski, 2020	No control, contact tracing strategies (manual tracing, DTC), testing, mass testing of all cases regardless of symptoms, self-isolation of symptomatic cases, quarantine
Ferrari, 2021	DTC
Wilmink, 2020	real-time DCT
Wallentin, 2020	Four scenarios: a) Continued lockdown; b) Stepwise relaxation of the lockdown; c) Relaxation of the lockdown paralleled with low, medium or high levels of DCT; d) Stepwise relaxation with monitoring and adaptive response

Ferretti, 2020	Isolation of symptomatic individuals, tracing and quarantining the contacts of symptomatic cases
Bulchandani, 2021	DCT, quarantine of infected population
Nuzzo, 2020	DCT, targeted self -isolation
Kim, 2021	DCT
Hinch, 2020	DCT, physical distancing, generalized lockdowns
Firth, 2020	DCT, quarantine
Peak, 2020	Individual quarantine or active monitoring of contacts (includes phone based self-monitoring)
Aleta, 2020	a) Unmitigated scenario (no interventions); b) LIFT scenario (the stay-at-home order is lifted after 8 weeks by reopening all work and community places, except for mass-gathering locations, a full lifting of all the remaining restrictions 4 weeks later while schools will remain closed; c) LIFT and enhanced tracing scenario - LET (the stay-at-home order is lifted, symptomatic covid-19 cases can be diagnosed and isolated at home and their household members are quarantined for 2 weeks)
Kretzschmar, 2020	a) contact tracing: conventional contact tracing and DCT; b) physical distancing and isolation for symptomatic individuals
Bicher, 2021	Six different strategies: 1 strategy without tracing (no tracing); 3 strategies with location tracing (household tracing, workplace tracing, combined household and workplace tracing); 2 strategies of DTC (persons using tracing devices, e.g., smartphone).

DCT, digital contact tracing

The quality assessment of the modeling studies, performed with the CHEERS checklist [9], showed that all articles, except four studies [41,43,54,55] had a structured abstract summarizing all important elements of the study. The introduction section of all 24 articles provided a broader context and relevance of the study. Nevertheless, the target populations and subgroups were not well analysed in some studies [38,39,44,48,53-56]. Also, the country or setting of the study was not specified in six articles [38,39,48,53,55,56]. Only Yasaka et al. [39] did not describe the analytic methods supporting the model. The values, ranges, references, and probability distributions for all parameters were lacking in three studies [37-39]; sources of uncertainity were missing as well in other studies [37-39,42]. The least reported item was the funding source [36-39,42,43,45,46,54,55,57], followed by the role of the funding body [35,40,47,51,53,58]. A conflict of interest statement was missing in three studies [38,46,54].

VI. Implications and limitations

The covid-19 pandemic has imposed serious challenges upon individuals, health care providers, and policy makers to curb the spread of the virus and limit human loss. Most countries in Europe and beyond have developed and are using different digital technologies and pathways to contain the pandemic. To this end, digital contact tracing has been a valuable approach, but must be combined with other preventive measures to reduce the reproductive number below one. The majority of the population, about 60% [37], has to use digital monitoring devices to obtain a significant effect. However, even with a lower uptake rate of the tools, digital contact tracing still reduces the number of infected individuals.

Digital contact tracing could reduce the reproductive number below one alone only if the entire population uses the digital devices and strictly adheres to preventive protocols (e.g., social distancing, hand washing, mask covering, quarantine, testing, vaccination). Recent events observed worldwide have demonstrated the impossibility of achieving 100% adherence to those measures (e.g., vaccine hesitancy, misinformation and disinformation related to covid-19, fake vaccination certificates or pass). These events are related to institutional distrust that has been exacerbated during the coronavirus pandemic. The causes of distrust towards national institutions and international organizations are related to general health literacy, vaccine literacy, but also to attempts of some government authorities to impose preventive measures. For instance, rendering monitoring devices (e.g., Spain, Austria) or covid-19 vaccination mandatory for the general population or specific groups (e.g., in Italy the vaccination is mandatory for health care workers). In addition, several data security and privacy breaches have been observed, limiting the use of the devices [19]. One of the reasons of concern is the use of centralized server protocols. These protocols have security, privacy issues and technical limitations that made some Member States to switch to the decentralized protocol which allows data to be stored on individual devices and not on a central server (e.g., Austria, Ireland, Italy, Germany and the UK) [19]. Although some countries modified the original versions of the applications, published the source code, nominated national authorities as data controllers according to the General Data Protection Regulation and recommendations of the European Commission, the damage had already been done and the uptake rate of the digital tools did not achieve the desirable level in most countries. Indeed, the level of implementation of the new technologies among the general population and health care providers is mostly low/medium across Europe. It should be noted, however, that the level of adoption increased during the pandemic (e.g., Germany). Even countries without a strong information and communication infrastructure started investing in digital applications at the outbreak of the pandemic (e.g., Lithuania, Serbia), while other countries strengthen their eHealth infrastructure (e.g., Finland).

Regarding limitations of the study, low response rate and language barriers were encountered in the cross-sectional study. However, it was a qualitative study and the data collected was sufficient to identify and describe digital tools and algorithms available in the participating countries. Also, some websites links provided by the participants were broken or discontinued, or the documents were not accessible. An overview of the literature was conducted to complete the information provided by the respondents. The language barrier, thus documents and websites available only in national languages, was resolved by translating the materials with Google translator or seeking the support of native speakers, when possible.

Limitations of the systematic review are related to articles available only as preprints, hence not peer-reviewed, or lack of full text articles that were eliminated from the study. This could impact the findings, but the included studies were informative and of medium to high quality. Furthermore, the uptake rates of the devices identified in the population-based studies, in terms of download and percentage of active users, were not referred to the entire population of the country under consideration but to the sample size of the study and were also reported differently in each study (e.g., percentage of enrolees that accepted to download and use the app, increment of the percentage of users during the study, number or percentage of notified cases). This rendered synthesis and comparison of the uptake rate practically impossible. However, the number of positive tests identified among active users of the devices indicates the effectiveness of contact tracing in identifying infected individuals and the level of implementation of the devices in the studied populations.

The findings of the present study emphasize the potential of contact tracing when properly implemented. The report will be published on the Health Information Portal of the PHIRI project (https://www.healthinformationportal.eu/) and could be used for the development of a good practice, which could be useful for future health emergencies. The lessons learned, in terms of security and privacy issues encountered in population health monitoring and surveillance, could be used for a capacity building course organized by the PHIRI project for health care professionals.

VII. Conclusions and recommendations

The addition of digital contact tracing to standard contact tracing and other preventive measures reduces the spread of the coronavirus, especially with a higher adoption rate of digital devices. The uptake rate has been influenced by several factors, such as privacy and security issues, misinformation and disinformation, knowledge and awareness among the general population, and skills of health care providers in information technology. Government authorities have also contributed to the lack of trust of the citizens in public health measures due to the lack of transparency and regulatory oversight in the development and implementation of the devices, and attempts to render public health preventive measures mandatory. The use of digital technologies according to data security and privacy regulation will preserve the rights and freedom of all citizens even in times of health emergencies. Targeted public health interventions to enhance health literacy and training programs for health professionals related to the use of information technologies could increase the implementation level of the new technological solutions and improve emergency preparedness towards future health threats.

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Appendices

Appendix 1: Survey instrument

SURVEY ON INNOVATIVE METHODS FOR HEALTH MONITORING IN EUROPE

Digital solutions addressing the covid-19 pandemic

Within PHIRI, *the Population Health Information Research Infrastructure*, Work Package 5 (WP), task 5.3.1 aims to develop and distribute a survey to investigate which innovative methods, state-of-the-art algorithms and digital tools (including social media, devices and artificial intelligence) are being used across different countries to monitor health issues related to COVID-19 in Europe, as well as who is using them. The survey addresses EU countries' representatives through National Nodes in WP4. Key considerations on the role of legislative and ethical aspects are also examined to provide context-relevant recommendations, facilitating innovation uptake and diffusion.

Introduction

Innovative solutions and digital tools are used to[1]:

- monitor the spread of the coronavirus
- research and develop diagnostics, treatments and vaccines
- ensure that Europeans can stay connected and safe online (e.g., protection from rising cyber attacks, scams, online risks for minors).

Innovative solutions include:

- *National contact tracing and warning apps*: can be voluntarily installed and used to warn users, even across borders, if they have been in the proximity of a person who is reported to have been tested positive for coronavirus. In the case of an alert, the app may provide relevant information from health authorities, such as advice to get tested or to self-isolate, and who to contact.
- *Artificial intelligence (AI):* can detect patterns in the spread of the coronavirus. With their help, public health sectors can monitor the spread of the coronavirus and quickly devise effective response strategies.
- *Online platforms fighting disinformation*: the EU Commission highlighted important actions to tackle COVID-19 disinformation and set up a program in 2020 to monitor the actions that platforms are taking to limit the spread of COVID-19 disinformation online, especially on social media (Google, Facebook, Twitter and Microsoft).

[1] EU Commission website, https://ec.europa.eu/info/live-work-travel-eu/coronavirus-response/digital-solutions-during-pandemic_en

Questionnaire

1. Which digital solutions addressing the covid-19 pandemic have been implemented in your country? Please, provide information on all digital solutions implemented in your country.

A. Digital tools used to monitor the spread of the coronavirus (e.g., national contact tracing and warning apps)

- If guidelines or best practices on digital tools are available in your country, please list the documents and/or links related to the tool(s): ____________________
- What is the uptake rate of the tool(s)? ____________________
- Have measures been adopted to evaluate the impact of the digital tool(s) (e.g., user surveys)? If 'yes', please specify the measures____________________
- Which are the target groups of the tool(s) (e.g., general population, healthcare workers, patients)?____________________

B. Digital tools used to research and develop diagnostics and teleconsultations

- If guidelines or best practices on digital tools are available in your country, please list the documents and/or links related to the tool(s): ____________________
- What is the uptake rate of the tool? ____________________
- Have measures been adopted to evaluate the impact of the digital tool(s) (e.g., user surveys)? If 'yes', please specify the measures____________________
- Which are the target groups of the tool(s) (e.g., general population, healthcare workers, patients)? ____________________

C. Digital tools/ online platforms used to monitor vaccination coverage levels/vaccine uptake

- If guidelines or best practices on digital tools are available in your country, please list documents and/or links related to the tool(s): ____________________
- What is the uptake rate of the tool? ____________________
- Have measures been adopted to evaluate the impact of the digital tool(s) (e.g., user surveys)? If 'yes', please specify the measures____________________
- Which are the target groups of the tool(s) (e.g., general population, healthcare workers, patients)? ____________________

D. Online platforms fighting disinformation, screening for food and non-food products with alleged healing or protective effects related to the coronavirus (e.g., Ebay, Facebook, Google, Microsoft)

Name of the platforms and/or links ____________________

2. Are specific algorithms (artificial intelligence) available in your country to detect patterns in the spread of the coronavirus (e.g., supercomputers)? If 'yes', please provide the title of the document(s) and/or link.

□ Yes ____

□ No

3. Are there information on legislative and ethical aspects related to the use of digital solutions addressing the covid-19 pandemic in your country (e.g., guidelines, reports)? If 'yes', please provide the title of the document(s) and/or link.

□ Yes ____

□ No

4. Do you have further information or comments about the implementation of digital tools and innovative solutions in your country?____

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