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An overview of reviews on digital health interventions during COVID- 19 era: insights and lessons for future pandemics

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Abstract

Background The COVID- 19 pandemic has significantly impacted global health, underscoring the crucial role of digital health solutions. The World Health Organization's Classification of Digital Interventions, Services, and Applications in Health (CDISAH) provides a framework for categorizing these technologies. This study aims to analyze the adoption and trends of digital health interventions during the COVID- 19 pandemic, mapping them to the CDISAH framework to identify the most and least utilized interventions and technologies.

Methods This overview-of-reviews study was conducted from 1 st January 2020 to 30 th December 2023, focusing on systematic reviews and meta-analyses retrieved from the Cochrane Database of Systematic Reviews, PubMed, Scopus, Web of Science, IEEE Xplore, and ProQuest. Additionally, gray literature was identified through searches on the Google Scholar platform and reviewing the citations and reference lists of the included studies. The findings were qualitatively mapped to the CDISAH framework.

Results A total of 64 review articles were analyzed. A content analysis of the included studies identified 292 codes related to healthcare providers, 257 codes related to data services, 88 codes related to individuals, and 43 codes related to health management and support personnel. The results revealed that the most frequent interventions were associated with telemedicine and data management subcategories, while gaps were identified in areas such as individual-based data reporting during the pandemic, highlighting the need for individuals to take a more active role in managing their own health in preparation for future crises.

Conclusions This study identifies both the strengths and weaknesses of the current digital health landscape. It emphasizes the transformative impact of digital health technologies during the COVID- 19 pandemic and provides a roadmap for future improvements in digital health interventions. By providing a comprehensive overview of digital health during this period, the study underscores the importance of implementing robust digital health strategies within the healthcare system to address existing gaps, leverage strengths, and enhance preparedness and resilience in future public health crises.

Keywords COVID- 19, Digital health, Digital health intervention classification, Health Policy

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Text box 1. Contributions to the literature

- Telemedicine has been the most utilized digital health intervention during pandemics.
- A shift towards crowd-sourced data over organizational data is essential for improving future pandemic responses.
- Digital interventions focused on data services saw widespread use, while those supporting health personnel were underutilized.
- The pandemic may signal a shift towards an AI-driven era, with data services at the core of health interventions.

Introduction

The 1918 influenza pandemic affected 27 percent of the world's population, causing an estimated 50 million fatalities. Similarly, the novel coronavirus- 2019 (COVID- 19) emerged in late 2019, spreading globally, and by August 2022, it had affected six percent of the world's population, causing over six million deaths [1]. A key difference between the two pandemics was the significant role digital solutions played in the fight against COVID- 19 [2]. The growth of digital health accelerated during the COVID- 19 pandemic, with ventures in this sector experiencing an unprecedented rise. Funding increased by 72% from the previous record set in 2018, reaching an all-time high of $26.5 billion [3].

Definitions of digital health in various studies typically refer to specific applications and technologies in this field [4–6]. However, digital health can be defined as the convergence of these technologies with health, healthcare, living, and society to provide quality care [7]. The COVID- 19 pandemic accelerated its shift from a luxury to a necessity due to social distancing measures [8]. Factors such as global internet accessibility, six-billion smartphone users, the influence of social networks in healthcare, and the use of clinical information systems facilitated this growh [7, 9]. The enduring positive impact of digital health interventions (DHIs) during COVID- 19 highlights the importance of leveraging the experiences and lessons learned [10].

The World Health Organization (WHO) introduced the Digital Health Intervention Classification (DHIC) in 2018, updated in 2023 as the Classification of Digital Interventions, Services, and Applications in Health (CDISAH). This classification is aligned with the International Standards Organization (ISO) System Category. and categorizes DHIs into four user groups: persons, healthcare providers, health management and support personnel, and data services. Each group's functionalities describe the capabilities of digital technologies aimed at achieving user-specific objectives, further organized into overarching groups [11, 12].

During the COVID- 19 pandemic, an avalanche of systematic reviews was published [13]. These reviews primarily focused on specific services and applications, such as telemedicine, mobile health, and artificial intelligence, during pandemics [7, 14]. Several of these reviews categorized functionalities using classifications other than CDISAH [6, 15]. The lack of a uniform classification basis for interventions could hinder the integration and comparison of study results. Alternatively, when CDISAH was utilized for categorizing interventions in studies, the classification process often remained restricted to high-level categories or target groups [16]. These articles offer substantial value for healthcare providers and policymakers, facilitating decision-making and evidence-based healthcare. Nevertheless, identifying and interpreting evidence from multiple systematic reviews, which are sometimes repetitive, confusing, or contradictory, is challenging. An overview of reviews can help address this challenge [17].

Given the explosion of digital health innovations during during the COVID- 19 era, providing an overview of these technologies and interventions can indeed be helpful in gaining insight into the frequency and trends of interventions in this field throughout the epidemic period. This comprehensive analysis can also serve as a valuable tool for identifying shortcomings in current approaches. Anticipating these shortcomings and planning accordingly will be essential for developing effective health strategies for future epidemics, as well as identifying the necessary points for the current focus of researchers and experts in the field of digital health. As a result, the present study aims to identify the trends of interventions and technologies used during the COVID-19 period to ascertain the most and least used interventions during this timeframe.

Material and methods

Study design

This overview of reviews study was conducted to identify systematic reviews (SRs) and/or meta-analyses published during the COVID- 19 pandemic, specifically addressing digital health interventions across various healthcare domains. The reporting guidelines employed in this overview were based on the fundamental principles outlined in the Preferred Reporting Items for Overviews of Reviews (PRIOR) statement from the EQUATOR Network [18, 19].

Search strategy

A comprehensive search for records was carried out from 1 st January 2020 to 30 th December 2023. The search was conducted in the English-language electronic databases, including the Cochrane Database of Systematic Reviews, PubMed, Scopus, Web of Science, IEEE Xplore, and ProQuest. Grey literature was identified by using the

Google Scholar search engine and reviewing the citations and reference lists of the included studies. The detailed search strategy is provided in Supplementary Table S1.

The databases, focused on the title and abstract, searched using terms related to three key concepts: "COVID- 19," "digital health applications and services," and"systematic review."Despite a great deal of scholarly work dedicated to the subject of digital health applications, a significant lack of common subgroup terminology persists. Consequently, to fulfill the aims of this overview, an additional collection of search terms was acquired from relevant systematic reviews and ISO-supplied key terms and concepts in digital health systems, as mentioned in the system category of the DHIC first edition [12, 20].

Eligibility criteria

The inclusion and exclusion criteria are shown in Table 1.

Study screening and selection

After removing duplicate records using EndNote 8, two reviewers (ZJ and NK) independently assessed a subset of references according to pre-established eligibility criteria. They conducted a comparison of the extraction results and obtained a significant kappa agreement of 0.78, as shown in Supplementary Table S2. Then, the two reviewers (ZJ and NK) conducted title/abstract and full-text screening. A third reviewer (FT), if necessary, resolved any disagreements through discussion and consensus.

Data extraction

The general characteristics of the included studies were systematically extracted by one reviewer (NK) using a predefined data extraction form. A second reviewer (ET) then checked the extracted data for accuracy and completeness. The extracted information included the following details: author name, year of publication, objective, participants, interventions, primary and secondary outcomes, searched databases, study design of included studies, qualitative assessment tool and its overall results, risk of bias assessment tool and its overall results, and study limitations.

Relevant findings from the included studies were extracted, and qualitative framework analyses were performed. The full texts of the included studies were imported into MAXQDA (version 18.2.5). Two reviewers (FT and ET) independently read the papers thoroughly. The findings from all included papers were coded and mapped to version two of CDISAH [21]. In cases where information from reviews was insufficient, primary studies were consulted. Any disagreement was resolved through discussions in multiple meetings.

Data synthesis

The purpose of this overview was to present and describe the existing body of evidence from systematic reviews. To achieve this, data synthesis was conducted to summarize and visualize the large amount of data extracted. Initially, one reviewer (FT) analyzed the extracted codes for each subcategory, highlighting key points and patterns. Similar codes were grouped and integrated to capture their essence in MS Word. Subsequently, two reviewers (FS and NS) checked the synthesized data for accuracy.

Table 1 Inclusion and exclusion criteria for systematic reviews on digital health interventions during COVID- 19 pandemic (2020–2023)

Study criteria	Inclusion criteria	Exclusion criteria
Study design	Systematic review or/and Meta-analysis	Primary studies, conference abstracts, letters to editors, commentaries, or other types of literature reviews
Population	Any population that received digital health interventions during the COVID- 19 pandemic	-
Interventions	Any systematic reviews and meta-analysis study concerning about digital health interventions and their functionalities during the COVID- 19 pandemic	Systematic reviews were excluded if they did not fit within the CDHIAS framework, either by solely mentioning technologies without discussing functionalities or by focusing on aspects such as patient experience, satisfaction, cost-effectiveness, opportunities, and challenges. Additionally, studies were excluded if they integrated multiple primary studies into non-CDHIAS frameworks, such as categorizing DHIs into care and follow-up interventions
Outcome	Digital health interventions' functionalities	Studies that did not provide enough information to be mapped with CDHIAS functionalities
Additional criteria	English language and full-text available studies	-

Critical appraisal assessments of included reviews

Two reviewers (ZJ and ET) independently assessed the methodological quality and risk of bias of each systematic review and/or meta-analysis using two assessment tools: A Measurement Tool to Assess Reviews (AMSTAR) 2 rating scale and the Risk of Bias in Systematic Reviews (ROBIS). The reviewers resolved their disagreements through discussion and consensus, with the assistance of a third reviewer (FT) when necessary. Based on AMSTAR 2 guideline outlined by Beverley et al. (2017), studies were categorized into four quality levels:

- High-quality reviews: These exhibit no or minimal weaknesses in critical domains
- Moderate-quality reviews: These contain more than one non-critical weakness but no critical flaws
- Low-quality reviews: These include at least one critical flaw, which may affect the reliability of their conclusions
- Critically low-quality reviews: These have multiple critical flaws, indicating a substantial risk of bias [22].

The ROBIS tool evaluates the risk of bias in systematic reviews across Phase 2 and Phase 3. Phase 2 has four domains: study eligibility criteria, identification and selection of studies, data collection and study appraisal, and synthesis and findings. The results for each domain and Phase 3 were categorized as follows:

- Low risk: Indicates that the review has been conducted with minimal bias, ensuring reliability and validity
- High risk: Suggests potential bias due to methodological shortcomings, which may compromise the trustworthiness of the findings.
- Unclear risk: Assigned when there is insufficient information to determine the level of bias [23].

Results

Search results and description of evidence

A total of 64 studies were included in this overview [24–87]. Fig. 1 shows the selection process for the included review studies. Approximately 30% of these included studies examined DHI during COVID- 19, focusing on the type of technology without limiting the scope to specific healthcare areas such as the use of AI during the COVID- 19 pandemic. Additionally, 39% of studies focused specifically on DHIs for COVID- 19, while 31% addressed DHIs in specific areas such as support for the elderly (n =4), rehabilitation (n =2), mental health (n =2), dermatology (n =2), pharmacology (n =1), and the management of special diseases like dementia (n =1), diabetes (n =1), and cardiovascular disease (n =1) during COVID- 19. The main characteristics of the included studies have been provided in Supplementary Table S3.

Methodological quality and risk of bias of reviews

According to the specified criteria of AMSTAR 2, the majority of the included studies (n =54) were rated as"critically low" [24–76, 87]. Other studies were classified as"low quality"(n =6) [81–86],"moderate quality"(n =3) [77–79], and"high quality"(n =1) [80]. Common methodological deficiencies were identified in items 1, 2, 7, 9, 10, 13, and 14. Further details are provided in Fig. 2 and Supplementary Table S4.

The included studies were also evaluated for bias using the ROBIS tool [5]. According to the criteria in Phases 2 and 3 of the ROBIS tool, approximately half of the included studies were deemed to have a"low risk"(n =33), 39% had an"unclear risk,"and 9% had a"high risk."Additional details are presented in Fig. 3 and Supplementary Table S5.

Description of mapping with CDISAH

After a comprehensive review of the included studies full texts using MAXQDA software, a total of 680 codes were extracted, elucidating the utilization of technologies for delivering healthcare interventions during the COVID- 19 pandemic. The corresponding number of codes related to each group is presented in Fig. 4. These codes were then analyzed, and the compiled results are demonstrated in Table 2. The Supplementary Table S6 also shows the items for which there was uncertainty during the analysis between two subgroups, as they were closely related to both groups. In the end, we chose one group, or in some cases, we could not select a subgroup and instead assigned it solely to its target group. This may indicate a limitation in the CDISAH framework's ability to classify interventions effectively.

It is important to note that the number of codes attributed to each category and subcategory may exceed the number of references listed for each subcategory, as the included studies were systematic reviews, where multiple interventions might be discussed within a single reference. Consequently, the findings indicate that the majority of DHIs during the COVID- 19 period primarily focused on healthcare providers (292), followed by data services (257), persons (88), and health management and support personnel (43). Further detailed information regarding each specific target group is elaborated upon in the subsequent sections.

Persons

Shows that during the COVID- 19 period, there were no interventions related to person-based reporting (1.5), and

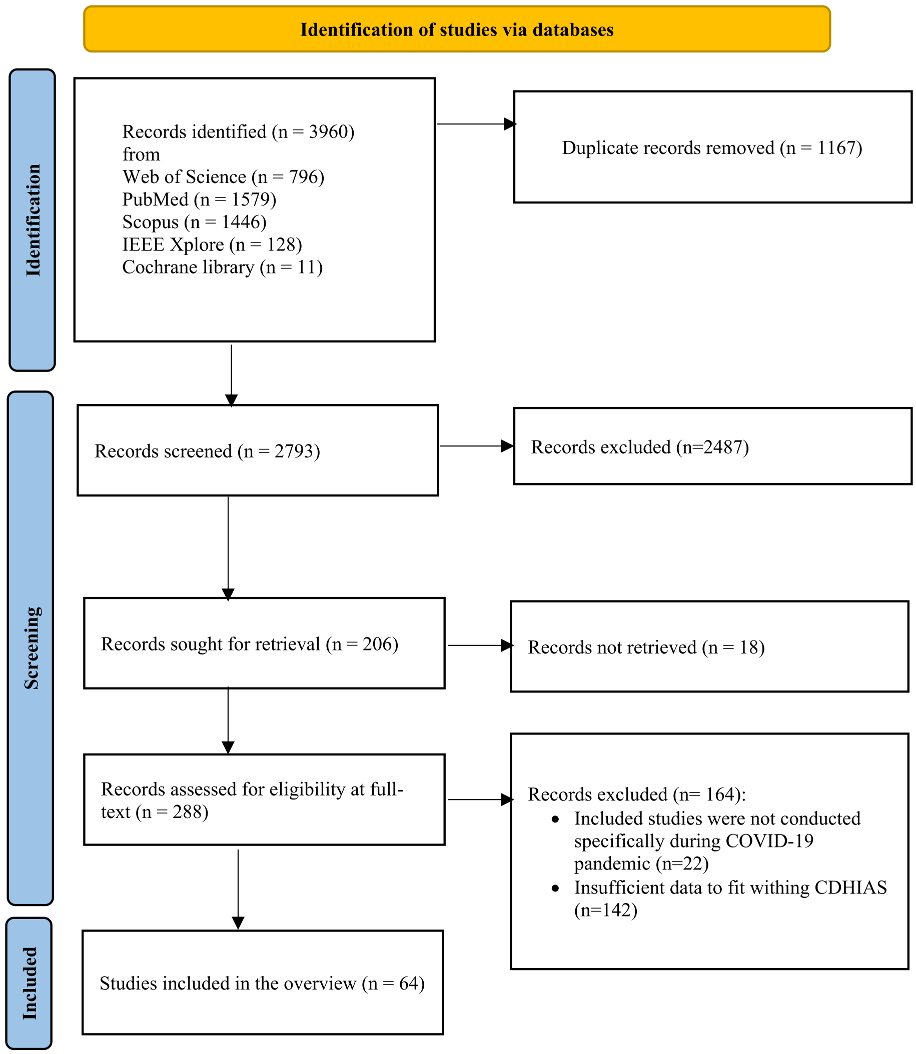

Fig. 1 PRIOR flow diagram of study selection process for systematic reviews on digital health interventions during COVID- 19 (2020–2023)

categories like person-centered financial transactions (1.7), consent management (1.8), and person-to-person communication (1.3) were infrequent.. The first two interventions involved managerial aspects such as billing and obtaining consent, while the third involved peer group discussions among patients (1.3). However, transmitting targeted health information (1.1.2) was the most common intervention for this group**.**

Within the overarching groups 1.1 and 1.2, healthcare facilities play a pivotal role in delivering health information, diagnoses, and reminders to patients using various technologies. These included television, radio, or digital billboards to raise community awareness about COVID- 19 (1.2.1) or telephone contacts to support special patients in their self-management of diseases (1.1.2). Alerts were also employed, either broadly, like robots sending warnings in crowds (1.2.2), or targeted, such as follow-up reminders (1.1.3).In groups 1.4 and 1.6, patients actively sought information online or through helplines (1.6.1), engaged in self-monitoring using wearable devices (1.4.2), or used mobile apps to remotely input data into their medical records (1.4.1). These independent actions empower patients to make informed health decisions.

Healthcare providers

The DHIs designed for healthcare providers stood out as the most frequent interventions among other target groups during the COVID- 19 pandemic, showing a broad spectrum of technologies aimed at improving patient care, optimizing workflows, and enhancing communication within the healthcare ecosystem. Among

Fig. 2 Quality assessment of systematic reviews on digital health interventions during the COVID- 19 pandemic

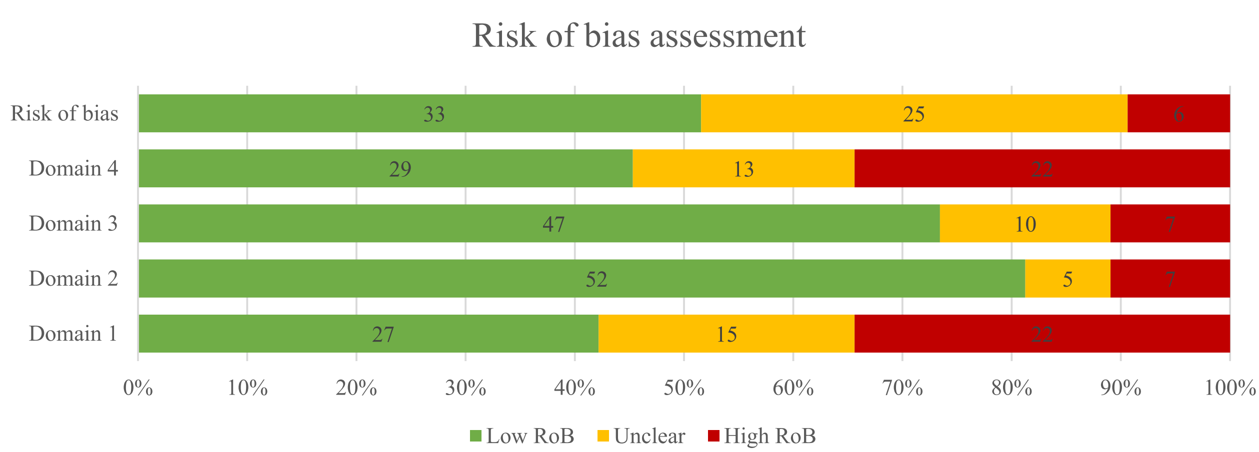

Fig. 3 Risk of bias assessment of included systematic reviews on digital health interventions during the COVID- 19 pandemic

these interventions, telemedicine (2.4) emerged as a central focus, offering a wide range of services. In terms of code frequency, it ranked second only to data management among all interventions.

Moreover, decision support systems (2.3) and scheduling and actively planning for healthcare providers (2.7) emerged as two other prominent areas, with frequencies of 31 and 24, respectively. Conversely, certain types of interventions, such as referral coordination (2.6), identification and registration of persons (2.1), and laboratory and diagnostic imaging management (2.10), were less common during the COVID- 19 pandemic. This suggests that these areas have potential for further development and investment. Of particular note, healthcare provider financial transactions (2.11) within the healthcare provider group lacked specific coding, indicating a potential

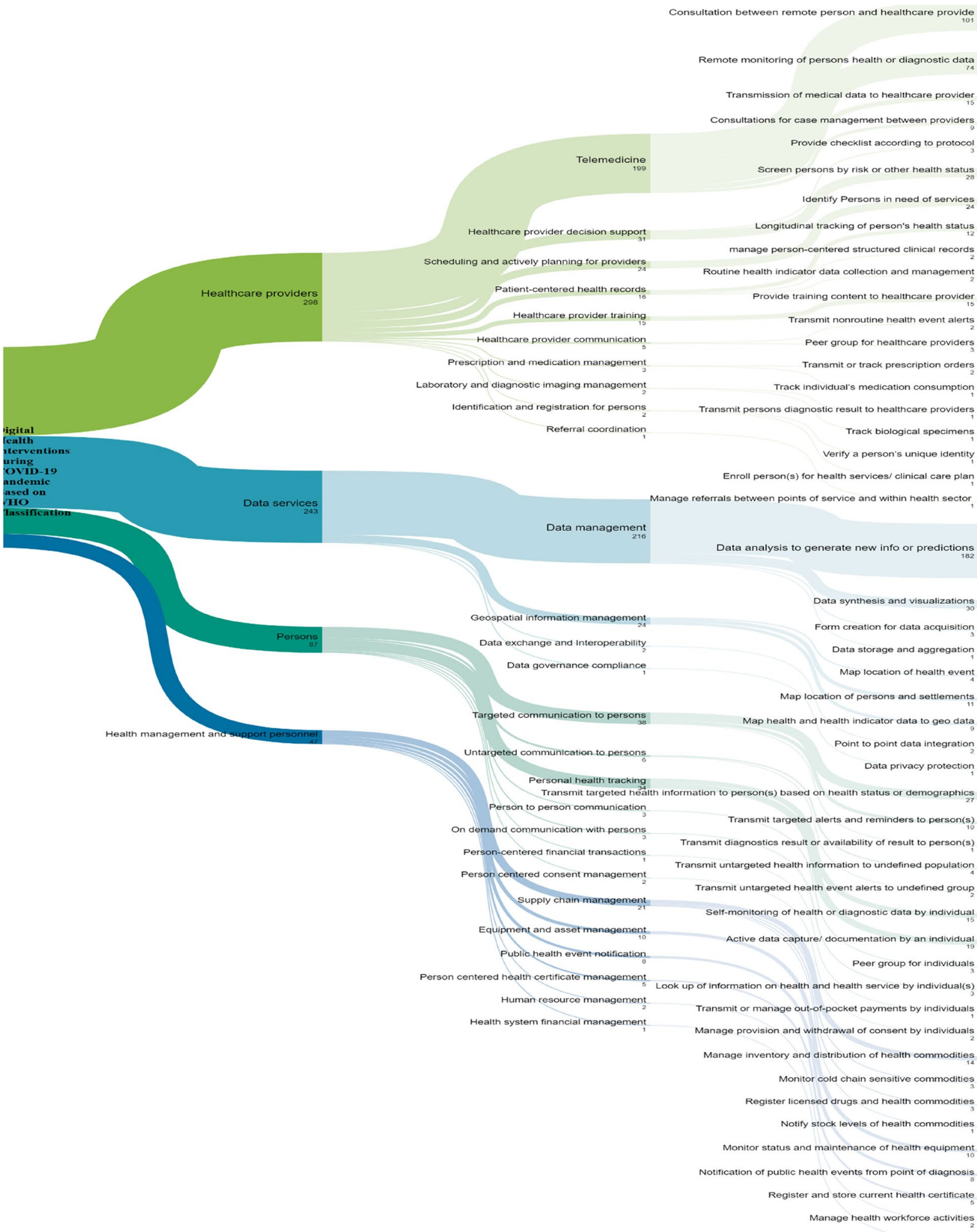

Fig. 4 Distribution of extracted codes for digital health interventions by target group using the classification of digital interventions, services, and applications in health

Table 2 Mapping digital health application and functionalities during the COVID- 19 pandemic (2020–2023) using the classification of digital interventions, services, and applications in health

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
1.0 DIGITAL HEALTH INTERVENTIONS FOR PERSONS (*n* = 87)	1.1 Targeted communication to persons (*n* = 38)	1.1.2 Transmit targeted health information to person(s) based on health status or demographics (*n* = 27)	**Online sessions** [28]**, web-based materials and systems** [29, 64]**, videoconferencing, text-messaging (SMS, WhatsApp, Telegram, Instagram or other social media platforms)** [34, 38, 51]**, telephone contacts** [45]**, applications** [31, 38, 51]**, videogames** [82]**, portals** [72]**, interfaces** [34]**, virtual assistance and chatbots** [38] are utilized for**:** Providing supervised session (with a tele specialist) or unsupervised materials to support self-management, self-care or self-administration. These technologies offer knowledge and motivational materials [31], related advice [47], and education and training materials [28, 29, 34, 38, 48, 51, 75, 77, 82] such as related exercises for overweight individuals or COVID- 19 related advice for patients with diabetes mellitus [28, 77]
		1.1.3 Transmit targeted alerts and reminders to person(s) (*n* = 10)	**Reminder systems, mobile application, and SMS** are utilized for: • Therapy adherence and medication reminders [38, 68] • Follow-up on healthcare services and appointment reminders [38] • Prompting individuals for self-isolation after close contacts of diagnosed cases [75] • Sending alerts and daily mood feedback about abnormal behavior based on deviation from usual life pattern for people with major depressive disorder [31] • Sending skill-based and mood messages for people with anxiety and depression [45]
		1.1.4 Transmit diagnostics result or availability of result to person(s) (*n* = 1)	**Phone calls, email, e-message (such as WhatsApp)** are utilized for**:** Transmitting patients'prescriptions during COVID- 19 [28]
	1.2 Untargeted communication to persons (*n* = 6)	1.2.1 Transmit untargeted health information to undefined population (*n* = 4)	**Radio and television programs, digital billboards, and printed media such as brochures, flyers and booklets, as well as videos on YouTube, and links to web-based tools** are utilized for: Disseminating information with various purposes including raising awareness about specific diseases [38], offering insights into health-related topics [29] [39], and providing patients with resources for self-management [28]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
		1.2.2 Transmit untargeted health event alerts to undefined group ($n = 2$)	**Prediction models** [85] are utilized for**:** Forecasting the peak time of the maximum number of active cases and the overall peak time in COVID- 19, enabling the sending of warning signals to the health systems. [85] **Robots** are utilized for: Broadcasting messages by analyzing the situation. For instance, during COVID- 19, in Singapore, the"Spot"robot estimates visitor numbers in specific locations and broadcasts messages about maintaining safe distances when crowds gather. [53]
	1.3 Person to person communication ($n = 3$)	1.3.1 Peer group for individuals ($n = 3$)	**Web-based platforms like Zoom (e.g., breakout room) or the chat function of Teams (Microsoft Corporation), as well as TikTok's "duet" or "react" functions, which allow users to add onto other participants'uploaded videos,** are utilized for: Facilitating connection and interaction among different groups of participants to share their experience with the group. This fosters engagement in health-related activities [29]
	1.4 Personal health tracking ($n = 34$)	1.4.2 Self-monitoring of health or diagnostic data by individual ($n = 15$)	**Wearable devices (such as patches, eyeglasses, smartwatches, shirts, skin-like patches), sensors (including thermal, humidity, acoustic, pressure, resistive, inductive, acceleration, electromyography, and impedance sensors), audio recorders, medical intelligent agents, coupled with analyzing technologies such as AI, fog/edge computing, IoT technologies, and smart phone apps** are utilized for**:** Collecting, analyzing, and reporting the health status of patients outside healthcare facilities to professionals or directly to patients for taking specific actions. For instance, a home-based rehabilitation system that recognizes the type and frequency of rehabilitation exercises performed by chronic stroke survivor during COVID- 19 by the user using a smartwatch and smartphone app equipped with an ML algorithm, a disease surveillance system to control pandemic, and real-time monitoring of blood pressure or electrocardiogram. [31, 33, 43, 46, 50, 53, 67, 75] **Zero-effort technologies** are utilized for: Prompting daily activities such as hand washing for patients living with dementia [68]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
		1.4.3 Active data capture/documentation by an individual (*n* = 19)	**Online self-reported questionnaires** are utilized for: Facilitating patients'self-monitoring and reporting data to professionals as needed. For instance, instructing eligible COVID- 19 patients to examine themselves and perform exhalation maneuvers to obtain Ruth score [28, 29, 34, 64] **Mobile or web applications or systems** are utilized for: • Collecting information from users to o Provide related alerts [75], assessment results [53, 73, 75], suggestions and related advices [30, 31] personalized recommendations [75], and predictions [31] o Support self-management [64, 75], self-scheduling [75], and self-reporting of disease [69, 75] o Improve patient engagement, for example, towards a healthy lifestyle [75] o Remotely record medical data and daily circumstances for health facilities [46] o Offer relevant advice to patient [30]
	1.6 On demand communication with persons (*n* = 3)	1.6.1 Look up of information on health and health service by individual(s) (*n* = 3)	**Web-based information** are utilized by: Individuals who voluntarily search for related information such as exercise guides [82] or are directed by their practitioners to look for information on the internet [29] **Helplines** are utilized by: By individuals seeking health-related information, such as HealthAlert, a WhatsApp-based helpline in Africa. This helpline employs automated response and triage to disseminating COVID- 19 related information from the national health department to the public [38]
	1.7 Person-centered financial transactions (*n* = 1)	1.7.1 Transmit or manage out-of-pocket payments by individuals (*n* = 1)	**Applications including Apple FaceTime, Facebook messenger video chat, Skype, and mobile health technology** are utilized for: Conducting billing of patients, thereby minimizing unnecessary exposure of hospital staff to patients and themselves during COVID- 19 [72]
	1.8 Person centered consent management (*n* = 2)	1.8.1 Manage provision and withdrawal of consent by individuals (*n* = 2)	**Digital platforms or patient portals of electronic medical record** are utilized for: Obtaining electronic informed consent from patients during a virtual visit [69, 72]
2.0 DIGITAL HEALTH INTERVENTIONS FOR HEALTHCARE PROVIDERS (*n* = 298)	2.1 Identification and registration for persons (*n* = 2)	2.1.1 Verify a person's unique identity (*n* = 1)	**Digital real-time healthcare systems** are utilized for: Analyzing biometric data in real-time and sending information via network to healthcare systems [46]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
		2.1.2 Enroll person(s) for health services/clinical care plan ($n = 1$)	**Phone call and patient portal** are utilized for: Enrolling individuals for health services, such as offering phone calls and completing pre-appointment documentation through patient portals integrated with HER in a clinic dedicated to providing primary and sexual healthcare during COVID- 19. [69]
	2.2 Patient-centered health records ($n = 16$)	2.2.1 Longitudinal tracking of person's health status ($n = 12$)	**Smartphone applications, smartwatches, wearable sensors and accessories, smart vital sign monitoring devices, blockchain-enabled IoMT**, **and opto-electronic micro-nano system** are utilized for**:** Conducting contact tracing [38, 53, 67, 73] and recording both active and passive patient data to tailor treatment plans [31] **Digital vaccine registry** [41]
		2.2.2 manage person-centered structured clinical records ($n = 2$)	**Medical records with pre-established format** are utilized for: • Allowing patients to remotely send information to their EHR. [28, 69] • Allowing all healthcare team members to complete medical records remotely [69]
		2.2.4 Routine health indicator data collection and management ($n = 2$)	**Mobile applications** are utilized for: Conducting contact tracing of people's movement during COVID- 19 to monitor, record, and alerts the proximity of events [75]
	2.3 Healthcare provider decision support ($n = 31$)	2.3.2 Provide checklist according to protocol ($n = 3$)	**Assessment tools, machine learning approaches, and CAD** are utilized for: Evaluating and Measuring clinical scores [61, 82] or analyzing and differentiating between various types of treatment plans [70] to aid physicians' decision-making
		2.3.3 Screen persons by risk or other health status ($n = 28$)	**AI and machine learning techniques** are utilized for: • Triaging COVID- 19 patients based on medical imaging or other clinical and surgical data stored in databases [71, 75]. For example, AI techniques can facilitate the detection and transfer of critically ill patients in hospitals with limited occupancy or capabilities [70] • Detecting changes in patient's clinical status by monitoring symptoms [30] • Aiding in diagnosis of COVID- 19 by combining chest CT-scan findings with other data such as clinical signs and symptoms, exposure history, laboratory tests, comorbidities, and infection-related biomarkers [30] [43, 44, 46, 53, 70, 78]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
			• Assisting healthcare professionals in making personalized treatment decisions for patients by automating the analysis of patient data and calculating the risks of COVID- 19 [43, 70, 71] • Classifying COVID- 19 using chest X-rays [30] **Digital phenotyping** is utilized for: Detecting mental disorders by using clinical recorded health data, call logs, message logs, app usage data, and self-assessment questionnaires filled by patients to [31] **Chatbots** are utilized for: Differentiating COVID- 19 from other diseases based on symptom data [75] **Diagnosing dashboard** are utilized for: Detecting COVID- 19 in patients by using data and medical images [32] **Drone and robot** are utilized for: Real-time case detection and screening [33] **Applications** are utilized for: Passively collecting data from video response of individuals, wearable wristband, and self-assessment questionnaires filled by patients for predictive purposes [31] **Screening systems** are utilized for: Identifying specific group of patients, such as a surveillance system based on EHR data to identify patients with non-marked improvement with antibiotics and alerting medical teams on daily bases [33], or for the follow-up of elderly individuals with COVID-19 [39] **Smart ontology based IoT system** are utilized for: Remote patient monitoring and early detection of COVID- 19 using biomedical signals from wearable sensors. Ontology provides the updated information of the COVID- 19 and makes decision-making easier for medical practitioners in emergencies [30]
	2.4 Telemedicine ($n = 199$)	2.4.1 Consultation between remote person and healthcare provide (n = 101)	**Video conferencing applications, interactive web-based management systems, store and forward systems, telephone contacts, social media messaging platforms or any messaging services, chatbots, emails, bi-directional radio and television programs, mobile or virtual applications** are utilized for: • Remote primary care delivery and outpatient appointments, addressing patient complaints, and providing consultation about necessary treatment to avoid physical contact between healthcare providers and patients in different fields such as orthodontic monitoring, consultation between patients and psychologists, teledermatology services like Dr.Connect

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
			system in Africa [25, 26, 28–30, 34, 36, 38, 45, 47, 48, 54, 58, 64, 68–70, 72, 76, 87] • Automated delivery and dispensing of medicine outside of patient care hours [38, 69] • Providing education materials on issues, coaching, or care and referral management. For example, providing personalized remote rehabilitation instruction for patients at home or educating COVID- 19 patients about healthy lifestyles or delivering breathing, aerobic, and lower limb muscle strength exercises to them [28, 38, 45, 64, 77, 82] • Empathic conversation and moods improvements by talking to patients. For instance, speaking to older patients to interrupt their social isolation during COVID- 19 [45, 50] • Online supervised guided group session such as web-based couple therapy, physiotherapy, and rehabilitation program [29, 39, 45, 77, 82] • Enabling clinical processes to be conducted remotely, i.e., treatment assistant program, therapy monitoring, or remote care services for patients, such as care service for patients with cognitive issues, respiratory-related diseases, and rehabilitation programs in patients with touch therapy, dance-therapy classes, or pulmonary rehabilitation program delivered by experienced physiotherapist [25, 29, 33, 34, 38, 47, 49, 68, 75–77, 82] • Guiding carers, family members, or housemates to support the treatment for patient at home. For example, for touch-based practices, they were asked to locate acupressure points or report back about how a body area felt. [29] • Tele diagnosing and remote screening patients for disease [53, 54]. For example, using **Robotic tele echography** for remote diagnosis of organs like lung and heart [53] • Tele triage to identify cases in need of consultation such as photo-triage of nonneoplastic and benign neoplastic lesions cases based on dermoscopy [58]
		2.4.2 Remote monitoring of persons health or diagnostic data ($n = 74$)	**The architecture of technologies in this part mostly comprises:** **Network layer, processing layer (Blockchain technologies, IoT computing, fog-cloud computing, AI), Detection and Sensor layer (Intelligent medical agents, Sensors (active and passive sensing technologies), non-wearable passive multiparametric sensors embedded in under mattress pads, wearable monitoring devices, smart devices, monitoring**

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
			systems, environmental sensing unit, portable electronic devices like blood pressure monitors, questionnaire), and Smart gateway (Phone calls, email, mobile applications) These technologies are utilized for: • Monitoring patients at their home (Home monitoring) and provide emergency satiation-based notification on the patient health status for concerned clinical authorities [26, 28, 31, 33, 34, 38, 43, 46, 47, 49–51, 53, 60, 67, 68, 72, 73, 76, 77, 82]. in situations such as: o Remote monitoring of patients who are home-quarantined due to COVID- 19 and alerting about quarantine violations o Post-operative follow-up o Therapy monitoring by telephone or email in patients with chronic inflammatory dermatoses o Monitoring system to detect early warning signs of impending symptomatic relapse or bipolar disorder o Monitoring of continuous positive airway pressure for obstructive sleep apnea to be passively evaluated by professionals every night o Home hospitalization system that sends patient information to the healthcare staff's smartphones fort proper action suggestions [67] o Computer vision-based assessment of motor functioning in patients with schizophrenia o Exploring quality of life in elderly population by questioners administered through phone calls o Monitoring mental health status and checking insomnia using wearable sleep trackers or pulse oximeters in clinical staff during COVID- 19 • Monitoring patients at healthcare settings to reduce patient and staff contact for frontline medical worker safety. The examples are: o Environmental sensing units installed in the hospitalization rooms to monitor patient status and vital signs o Robots stationed in departments such as ICU with COVID- 19 patients to provide monitoring o Automated imaging workflow during the COVID- 19 pandemic allow for patient monitoring from remote centers o Wearable health equipment to monitor oxygen saturation, temperature, heart rate, and respiration rate to ensure the safety of frontline medical worker o Virtual ward rounds conducted by specialists involve receiving real-time audiovisual information from a resident in the ward wearing smart glasses integrated with telemedicine [28, 46, 47, 51, 53, 67, 70]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
		2.4.3 Transmission of medical data to healthcare provider ($n = 15$)	**Smartphone is** utilized for**:** • Passively sending recorded data to providers using the store and forward method [26, 31, 76]. For example, tele dermatology in patients with COVID- 19 involves using the store and forward method to transmit data • Real-time sending of data, alerts and notifications to concerned clinical authorities [26, 43, 67, 68, 70]. For example, real-time data of isolated patients reporting their symptoms and disease progression
		2.4.4 Consultations for case management between providers ($n = 9$)	**Mobile and social media apps (e.g., WeChat, WhatsApp), Teleconferencing platforms, mobile app, web-based session, and mobile telehealth system** are utilized for: • Tele mentoring, seeking advice from other professionals such as asking advice from pharmacists [48] • Consultation between providers to support case decisions [25, 69] • Academic discussion [26, 28] • Sharing knowledge on a specific technique between experts [29] • Remote psychological support for healthcare professionals [65]
	2.5 Healthcare provider communication ($n = 5$)	2.5.4 Transmit nonroutine health event alerts ($n = 2$)	**AI approached** are utilized for: Alerting new research papers and other materials to researchers [53]
		2.5.5 Peer group for healthcare providers ($n = 3$)	**Virtual groups in social media platforms, mobile apps, and support hotlines for providers** are utilized for: Facilitating knowledge sharing, such as junior medical students connecting with senior medical students during COVID- 19 under the supervision of expert faculty members [33, 65]
	2.6 Referral coordination ($n = 1$)	2.6.2 Manage referrals between points of service and within health sector ($n = 1$)	**Telephone calls** are utilized for: Contacting patients by providers after discharge and referring them to appropriate rehabilitation providers based on complains [39]
	2.7 Scheduling and actively planning for providers ($n = 24$)	2.7.1 Identify Persons in need of services ($n = 24$)	**AI model** are utilized for: Triaging patients with risk scoring from blood samples [53] **Robots** are utilized for: Carrying out a series of monitoring evaluations capable of providing triage for hospital patients and telecritical care in hospital setting such as Dr. spot robot [53] **Active phone calls** are utilized for: Screening, diagnosing and evaluating suspicious COVID- 19 cases [34]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
	2.8 Healthcare provider training ($n=15$)	2.8.1 Provide training content to healthcare provider ($n=15$)	**Video conferencing platforms (e.g., Zoom and Blackboard) or informal platforms such as WhatsApp** [38, 69]**, live video broadcasts** [72]**, modifiable web-based handbooks** [65]**, e-learning package** [65, 79]**, tele-education resources** [38]**, online resources** [33, 38, 65, 69]**, online games** [65]**, and mobile applications** [69] are utilized for: • Providing training to health personnel [33, 38, 65, 69, 79] • Offering well-being advice to healthcare personnel [65]
	2.9 Prescription and medication management ($n=3$)	2.9.1 Transmit or track prescription orders ($n=2$)	**SMS and email** are utilized for: Sending E-prescription to the patients or directly to pharmacies for the delivery of medicine to patients' homes [28, 38]
		2.9.2 Track individual's medication consumption ($n=1$)	**Tele-case-management systems** are utilized for: Continuously monitoring and managing the patient's medication regimen according to the patient's conditions [48]
	2.10 Laboratory and diagnostic imaging management ($n=2$)	2.10.1 Transmit persons diagnostic result to healthcare providers ($n=1$)	**Teleradiology systems** is utilized for: Transmitting radiological images of patients from one geographical location to another, enabling the provision of radiological services to healthcare institutes in rural areas in the absence of radiologists [38]
		2.10.4 Track biological specimens ($n=1$)	**Telehealth care-based mobile phone and PDA technology using IoT** are utilized for: Tele laboratory or tele-medical laboratory services, wherein clinical exams are performed on patients directly in a hospital by technicians through IoT medical devices. Results are automatically sent via the hospital cloud to doctors of hospitals for validation and/or consultation [33]
3.0 DIGITAL HEALTH INTERVENTIONS FOR HEALTH MANAGEMENT AND SUPPORT PERSONNEL (47)	3.1 Human resource management ($n=2$)	3.1.5 Manage health workforce activities ($n=2$)	**Applications such as Apple FaceTime, Facebook Messenger video chat, Skype, Mobile health technology, and software robotics bot** are utilized for: Developing staffing plans [72] or for real time workers management. For example, **software robotics bot** enables the monitoring of employees'health conditions and the flagging of their status in case of any suspicious condition such as high body temperatures to enable the relevant authorities to initiate proper actions promptly [53]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
	3.2 Supply chain management ($n = 21$)	3.2.1 Manage inventory and distribution of health commodities ($n = 14$)	**AI and machine learning** are utilized for: • Mapping proper prioritization and resource allocation of detected supplies [70] • Queuing model for hospital bed allocation in the ICU [53] **Drones, robots and block-chain enabled IOMT** are utilized for: Delivering medical supplies, food, equipment, patient laboratory samples, and other supplies between different stations to healthcare workers and patients, as well as for waste management [46, 53, 70] **Dashboard** are utilized for: Effectively prioritizing clinical care and allocating scarce resources [32]
		3.2.2 Notify stock levels of health commodities ($n = 1$)	**Tele-critical care services** are utilized for: Monitoring ICU resources such as occupancy and available ventilators to coordinate the transfer of critically ill patients in hospital with limited capabilities [70]
		3.2.3 Monitor cold chain sensitive commodities ($n = 3$)	**Digital or AI-based wearable devices (e.g., non-contact infrared digital thermometers used to measure body temperature for COVID- 19 screening) and electronic equipment** are utilized for: • Mentoring individuals to assist them in self-management of health behaviors [38] • Protecting healthcare workers, for example, using electronic personal protective equipment to prevent COVID- 19 infection [75]
		3.2.4 Register licensed drugs and health commodities ($n = 3$)	**Digital commercial carts** are utilized for: Providing hospital medication coverage outside the hours of patient care in rural hospitals and ensuring critical medication access [69]
	3.3 Public health event notification ($n = 8$)	3.3.1 Notification of public health events from point of diagnosis ($n = 8$)	**Drones with scanners and high-resolution cameras** are utilized for: • Prompting offenders of public health mandates visually or auditorily [70] • Reporting health policies violations to the relevant authorities [70] **Contactless screening systems, blockchain apps, big data, and AI methods** are utilized for: Autonomous assessing of individuals' eligibility regarding specific health issues and reporting to relevant authorities, such as determining an individual's eligibility to enter a territory during COVID- 19 [53], alerting outbreak surveillance about such cases [46, 75], or monitoring the spread pattern of COVID- 19 virus for researchers, agencies, and government [33]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
	3.5 Health system financial management ($n = 1$)	3.5.3 Transmit and manage payments to health facilities ($n = 1$)	**Applications including Apple FaceTime, Facebook Messenger video chat, Skype, and Mobile health technology** are utilized for: Conducting billing of patients [72]
	3.6 Equipment and asset management ($n = 10$)	3.6.1 Monitor status and maintenance of health equipment ($n = 10$)	**AI-based systems** are utilized for: Optimizing a queueing model for hospital bed allocation in the ICU, proposing an optimal admission rate and estimating the costs associated with increasing capacity and refusing patients [86] **Dashboards** are utilized for: Monitoring information about hospital beds to manage them effectively [32] **Robotics** are utilized for: Disinfecting patient rooms, corridors, and other units in hospitals. For example, by decomposing DNA structures of viruses, bacteria, and other types of harmful organic microorganisms with UV light, such as Bucharest Robot and UVD from Denmark, YOUIBOT from Singapore, Nimbus from Scottish company, and Xenex [53]
	3.8-person centered health certificate management ($n = 5$)	3.8.1 Register and store current health certificate ($n = 5$)	**Digital COVID- 19 vaccination certificates** are utilized for: Providing proof of COVID- 19 vaccine for entry permission to different events, international travelling, and measuring the global vaccination rate [41]
4.0 DIGITAL HEALTH INTERVENTIONS FOR DATA SERVICES ($n = 243$)	4.1 Data Management ($n = 216$)	4.1.1 Form creation for data acquisition ($n = 3$)	**Web-based or cloud platform and mobile apps** are utilized for: Recording health parameters, such as health declaration forms in airport, to identify high risk travelers for quarantine [30, 75]
		4.1.2 Data storage and aggregation ($n = 1$)	**Cloud storage services** are utilized for: Storing data from different systems, such as IoT sensors [30]
		4.1.3 Data synthesis and visualizations ($n = 30$)	**Dashboards** are utilized for: • Representing and monitoring the prevalence of COVID- 19 [32] • Tracking COVID- 19 verification in real-time [32] • Managing the performance of hospital units like laboratories [32] • Monitoring emotions on social media during COVID-19 [29] • Supporting decision making by visualizing trends and forecasts [32] • Predicting the level of quarantine area based on location and distance data [32] **AI models** are utilized for:

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
			• Simulating the dynamics of COVID- 19 and the effects of different control measures on hospitalization [52, 67, 78, 85] • Assisting in the diagnosis and classification of COVID-19 by using detection techniques on medical images [63] • Contributing to COVID- 19 drug development, drug repurposing (the application of approved drugs to new therapeutic indications), or drug repositioning to find effective drugs against COVID- 19 [53, 78] Developing effective and safe vaccine for COVID- 10 [78] **Databases powered by AI approaches** are utilized for: Knowledge dissemination and collecting scientist's insights and innovations [70] **Knowledge graph** are utilized for: Biomedical knowledge graphs used by researches to identify potential candidate drugs for COVID- 19 [53]
		4.1.4 Data analysis to generate new info or predictions ($n = 182$)	**AI models and bots powered by analyzing large amount of data from different sources like hospital units, social media, searches in Google Trends, and GitHub repositories** are utilized for: • Predicting: o Number of positive cases, recovered cases and deceased cases or evolution and spread of COVID-19 in a specific region or time period [52, 66, 70, 78, 85] o Patient diagnosis or prognosis [30, 35, 37, 40, 44, 52, 55, 57, 59, 62, 63, 66, 71, 74, 81] or discriminating between positive and negative cases of COVID- 19 [43, 74, 85] or COVID- 19 and other pneumonias [57, 80, 84] using data such as medical images and lung sounds [30] o COVID- 19 outbreaks [44, 52, 66, 85] [75] o Ways of COVID- 19 transmission and pattern [37, 52, 66, 85] o Classifying lung disease severity [52, 53, 71] or patient categories (severe, mild) [30] [66] [74] and triaging patients with risk scoring from blood samples [53] o Early diagnosis of severe condition of COVID- 19 [40, 57, 62, 73, 78] o Clinical outcomes like required hospital beds, ventilators, length of hospital stay, and ICU admission [24, 52] [85] [66] [86] [70] [71]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
			o Outcomes such as survival or death for severe COVID- 19 patients [27, 52, 57, 71, 78, 83] o Impact of other factors such as weather variables on the transmission of COVID- 19 [85] o Adverse events associated with possible pharmacotherapies of COVID- 19 patients such as cardiac problems [27] o And extracting new information, such as relevant indicators for COVID- 19 disease classification [30, 78] or identifying the suitable donors of recovered COVID- 19 patients to help severe cases by analyzing antibodies data [70] • Drug discovery and development such as Baricitinib or vaccine development [42, 53, 56, 70, 78] • Identifying potential therapeutic agents against COVID- 19 by analyzing datasets [78] • Analyzing medical image features for COVID- 19 diagnosis [40, 44, 53, 57, 62, 63, 74, 75, 78, 85] **Healthcare applications that passively collect data in the form of questionnaires or electronic forms** are utilized for: • Predicting new health information, such as analyzing step counting to predict changes in depression level [31], analyzing signs to predict symptomatic worsening to avoid relapse [24, 31], analyzing phenotyping data to distinguish between healthy participant with those with schizophrenia [31], or analyzing daily subjective mood based on patients' daily self-assessments [31] • Finding relationship, such as relation between depression and time spend at home [31], the frequencies of keywords related to COVID- 19 used in social media and early detection of disease outbreaks [75], or change in behavior and mental health of college students in response to COVID- 19 [73] • Monitoring and tracking the epidemiological spread of COVID- 19 and its future spread [85] **Data augmentation of COVID- 19 X-ray images** [30]
	4.3 Geospatial information management (24)	4.3.2 Map location of health event ($n = 4$)	**AI algorithms and health sensor technologies** are utilized for: Detecting disease outbreak [33] or forecasting the growth of epidemics in specific regions. [74] **Dashboards** are utilized for: Providing geographical representation to identify patterns of spatial–temporal dispersion during the pandemic [32] **Drones** are utilized for: Providing aerial supervision of health regulations [70]

Table 2 (continued)

Target group (number of codes)	Overarching group (number of codes)	Intervention (number of codes)	Digital health applications and Functionalities
		4.3.3 Map location of persons and settlements (n = 11)	**GPS, GIS, IoT-based systems, and wearable technologies** are utilized for: Reporting the location of diagnosed cases, hospital occupancy, and patient compliance with public health regulations to guide interventions for COVID- 19, spatial decision support, and real-time surveillance [33, 43, 70] **Mobile applications utilizing bluetooth or AI operation** are utilized for: Contact tracing, monitoring people's movement, and proximity to a known COVID- 19 case [70, 75] **AI algorithms** are utilized for: Building a predictive model to predict people and areas with high risk of COVID- 19 and grouping cities into clusters based on transmission patterns [27, 52]
		4.3.5 Map health and health indicator data to geo data (n = 9)	**AI algorithms and dashboard** are utilized for: Representing and modeling epidemiological spread pattern of COVID- 19 and predicting its transmission, clusters, and hot spots based on geographic location [32, 52–54, 85]
	4.4 Data exchange and Interoperability (2)	4.4.1 Point to point data integration (n = 2)	**Blockchain-based platforms** are utilized for: COVID- 19 electronic medical records sharing among hospitals all over the world [67] **IoT or web-based systems** are utilized for: Communication channels between medical devices [70]
	4.5 Data governance compliance (1)	4.5.2 Data privacy protection (n = 1)	**Blockchain-based support platforms** are utilized for: Ensuring patient privacy in sharing COVID- 19 electronic medical records among hospitals all over the world [67]

gap in digital health. Some items related to telemedicine could not be further categorized based on functionalities indicated in Supplementary Table S6.

Health management and support personnel

The qualitative analysis of DHIs for health management and support personnel reveals them as the least frequent target group, with only 47 codes identified. The overarching groups of civil registration and vital statistics (3.4) and facility management (3.7) within this target group lack related codes, suggesting potential areas for further investigation. The majority of interventions in this group are concentrated in supply chain management (3.2), with a particular focus on managing inventory and distributing health commodities (3.2.1). Digital COVID- 19 vaccination certificates and digital commercial carts are unique technologies tailored to the specific needs of this target group. Additionally, technologies such as artificial intelligence (AI), drones, dashboards, and web-based applications witness widespread adoption, aligning with trends observed across other target groups. Three items related to this target group could not be further categorized based on functionalities which are indicated in Supplementary Table S6.

Data service

Despite the healthcare provider target group receiving the majority of interventions during the COVID- 19 period, data management, as an overarching category within the data service target group, received the most attention with 216 intervention codes. The COVID- 19 period employed a diverse array of digital technologies to acquire, store, aggregate, analyze, visualize, and generate information, highlighting the increased importance of data management. In this target group, geospatial information management (4.3) ranked second in terms of intervention codes, with AI playing a significant role in facilitating such interventions. Nevertheless, data coding (4.2) within the data service group did not yield any extracted codes, indicating a need for further discussion regarding the significance of this group and analyzing potential interventions for future pandemics.

Discussion

This overview synthesizes evidence from review studies focusing on DHIs, applications, and services during the COVID- 19 pandemic, mapped against version 2 of the CDISAH. By integrating studies from diverse healthcare domains with varying aims, technologies, and organizational contexts, this work provides a comprehensive picture of DHIs during the pandemic. The broad scope of this synthesis enables the identification of both underrepresented innovations and dominant trends. For instance, it highlights technologies with limited adoption, such as 3D printing for medical equipment, electronic personal protective equipment (ePPE), and robotics used for remote surgery, tele-physiotherapy, or as physician assistants—technologies that were not explicitly addressed in the CDISAH framework. At the same time, it captures highly prevalent trends, such as the widespread adoption of telemedicine and the analysis of large-scale health data for predicting COVID- 19 cases, peak infection periods, transmission pathways, disease outcomes, drug discovery, and other critical applications.

The findings within the “person” target group can be discussed in alignment with Brabham’s continuum of user participation in healthcare activities and crowdsourcing processes [88]. In line with this continuum, the CDISAH subcategories of “targeted and untargeted communication to persons” reflect a “traditional top-down hierarchical process” where the locus of control is with organizations and they proactively disseminate information to people. Conversely, “on-demand communication with persons,” “person-based reporting,” and “person-to-person communication” subcategories signify a “bottom-up grassroots process,” where individuals play a key role. Additionally, “person-centered consent management,” “person-centered financial transactions,” and “personal health tracking” represent a “shared top-down and bottom-up process” where control is distributed between organizations and the online community.

The study findings reveal that over half of the extracted codes within the “person” target group are attributed to the traditional top-down hierarchical process, while bottom-up grassroots processes account for only 7% of the codes, with"person-based reporting"having no associated codes. This absence is significant given that crowdsourced data is a crucial information source during crises [89]. This finding is consistent with Xiong et al.’s study on DHIs in primary care for non-communicable disease management, which also found a lack of codes for"person based reporting"and “client financial transactions” [90]. Moreover, the “shared top-down and bottom-up process” comprises 42% of the total, with"personal health tracking"being particularly prominent.

These findings highlight the shift from traditional top-down approaches to crowd-based services, which has been facilitated by greater accessibility to the internet and mobile phones, as well as advancements in high-tech technologies like zero-effort technologies. As these innovations continue to evolve, patients will increasingly play a more active role in managing their health, a development that is especially critical during pandemics [89]. To effectively support this transition, there is a need for growth in areas such as patient empowerment, patient engagement, and consumer health informatics.

In the "healthcare providers" target group, telemedicine interventions dominated, representing 67% of codes within this group and 30% of overall codes. This finding was anticipated, as telemedicine has been reported as the most prevalent published topic in health information technology from 2000 to 2019, with numerous studies documenting a global increase in its use during the pandemic compared to 2019 rates [91–93].

During this overview, certain interventions involving robots assisting healthcare providers in conducting procedures, particularly surgical procedures, and delivering patient care by mimicking human movements from a safe distance were identified. These telerobotic systems align with the concept of telemedicine [94] but do not fit within the subcategories of CDISAH. Our findings suggest a potential need to revise the telemedicine subcategories to more comprehensively encompass the interventions.

Moreover, some experts encountered challenges in assigning correct subcategories to some interventions due to overlapping subcategories. For instance, the subcategory "2.4.4 consultations for case management between healthcare providers" closely overlaps with "2.5.5 peer group for healthcare providers." While the CDHAS introduction acknowledges that an intervention may have multiple functions and could fit into several subcategories [11, 12], it can be argued that the principles of clarity and mutual exclusivity are critical for an effective classification system. Clarity ensures that there is no confusion regarding the placement of any data item, and mutual exclusivity guarantees that each item fits distinctly into one category [95]. Therefore, it may be beneficial to reconsider and refine certain subcategories within the CDISAH to enhance the system's effectiveness.

" Health management and support personnel" emerged as the least frequent target group, accounting for only 7% of all extracted codes. Consistent with this finding, the study by Xiong et al. also reported an absence of DHIs tailored for this target group [90]. The most prevalent intervention within this target group was "supply chain management," while the "Civil Registration and Vital Statistics" and "facility management" subcategories lacked codes. This absence may stem from the foundational and long-term nature of these interventions, resulting in comparatively less emphasis during the rapid transition to digital health amid the COVID- 19 pandemic. Nevertheless, these findings underscore a gap and a potential vulnerability in DHIs deployment during crises. Future studies and interventions should prioritize addressing the needs of this target group. Additionally, policies and strategies aimed at addressing these areas should be developed to mitigate risks in future crises.

Furthermore, within the scope of the present overview, two interventions were identified that considered DHI for healthcare personnel, yet couldn't be fit into the existing subcategories. These interventions were three-dimensional printing for the rapid production of crucial medical supplies and electronic personal protective equipment to prevent infection. This suggests the need for a revision of CDISAH to comprehensively encompass such interventions.

This study reveals that the broadest category of DHIs was centered around "Data services" target group, constituting 36% of all codes. Within this group, there were no intervention related to data coding and data management accounted for 89% of the codes. This emphasizes the importance of data-oriented approaches during pandemics, as accurate and timely data are critical for crisis management [89].

Overall, this study contributes to the identification of existing strengths and weaknesses in digital health within the healthcare system. During the COVID- 19 pandemic, technologies such as big data analytics, AI and machine learning, blockchain, and m-health have demonstrated their potential in addressing healthcare challenges through data-driven approaches. Multiple studies confirm the accelerated adoption of novel health information technologies amid the COVID- 19 pandemic [96]. This transformative period, characterized by a "digital revolution" driven specifically by the integration of AI and advanced technologies, signifies a shift beyond the information era [97]. As it is claimed [97], this time may be the brink of entering the AI era, in which interventions increasingly revolve around data services, empowering individuals to take more prominent roles in managing their healthcare. Since the evolutions can run backward, future studies should not only focus on strengthening identified weak points but also on sustaining the momentum of these current advantages, especially telemedicine and AI, to ensure continued progress in digital health.

The resulting holistic overview of digital health advancements in this study offers valuable insights that can be leveraged by healthcare organizations to refine future trend analyses, inform strategic decision-making, and implement evidence-based policies. This synthesis not only supports the optimization of digital health integration for future public health emergencies but also provides a foundation for refining existing frameworks, such as CDISAH, to better account for evolving technologies and their functionalities in healthcare. Furthermore, mapping these interventions to the CDISAH framework facilitates a structured analysis of their impact, revealing critical gaps in areas such as person-centered data reporting and healthcare workforce support.

Like any overview of review studies, this research is subject to certain biases that warrant discussion. Selection bias is a primary limitation, as the inclusion of only English-language studies may have influenced the observed trends and findings. To mitigate this, a broad range of databases and gray literature sources were used to ensure diverse global representation. The inclusion of studies from various countries further supports the generalizability of the findings and helps reduce the potential impact of language-related bias.

Additionally, there is a risk of synthesis bias, as the experts involved in reviewing and classifying the studies were primarily from a single country. This could introduce contextual or cultural biases in the interpretation and allocation of functionalities, suggesting that the findings of this study may vary if conducted in different countries due to differences in healthcare infrastructure, digital health policies, and socioeconomic conditions. To address this, three specialists with extensive expertise in digital health were involved in the classification process, enhancing the robustness and generalizability of the findings. Furthermore, the use of the CDISAH, an internationally recognized framework, was intentional. Unlike ad hoc or context-specific classification systems, CDISAH's clarity and specificity can reduce the likelihood of subjective interpretations, ensuring that individuals with diverse backgrounds can consistently assign codes to interventions. This approach minimizes errors and enhances the reliability of the findings, making them more applicable across different healthcare settings and countries.

Moreover, due to the high volume of publication during the COVID- 19 pandemic this study was limited to systematic reviews, which may lead to overlap among the included primary studies. However, considering the research objective of mapping interventions and the thorough process of checking and synthesizing the extracted codes, this overlap is unlikely to significantly affect the overall results.

Despite these efforts, variations in healthcare policies and digital health governance across countries may still influence the applicability of our findings. To enhance the validity and applicability of future research, we recommend incorporating meta-analyses where possible to provide quantitative validation and conducting subgroup analyses to evaluate the impact of digital interventions across specific populations and contexts. Additionally, longitudinal studies tracking the sustained adoption and effectiveness of digital health solutions beyond the pandemic would strengthen the evidence base for long-term digital health strategies. Furthermore, engaging with policymakers and healthcare providers from diverse regions to co-design and validate digital health frameworks, such as CDISAH, could ensure their relevance and adaptability to local contexts. These steps would not only improve the generalizability of findings but also support the development of more inclusive, context-sensitive, and effective digital health strategies for future public health crises.

Conclusions

This study provides a comprehensive overview of DHIs employed during the COVID- 19 pandemic, mapped to the CDISAH. By analyzing trends and utilization patterns, it highlights both the strengths and limitations of current digital health capabilities within the healthcare system. Furthermore, this study provides a roadmap and emphasizes the critical need for integrated digital health strategies to strengthen healthcare systems'preparedness and resilience against future public health crises. The insights gained from this review also lay the groundwork for further exploration of CDISAH classification framework, with potential future applications in refining and evaluating its structure to better align with emerging digital health trends.

Abbreviations

CDISAH	Classification of Digital Interventions, Services, and Applications in Health
DHIs	Digital health interventions
WHO	World Health Organization
ISO	International Standards Organization
DHIC	Digital Health Intervention Classification
PRIOR	Preferred Reporting Items for Overviews of Reviews
AMSTAR	A Measurement Tool to Assess Reviews
ROBIS	Risk of Bias in Systematic Reviews
AI	Artificial intelligence

Supplementary Information

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Supplementary Material 1.

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Authors' contributions

F.S. and F.T. conceptualized this review. F.S., F.T., and E.T. were responsible for overseeing library resources and supervising the retrieval of resources from databases. E.T. and N.S. conducted the relevant searches. F.S., F.T., and E.T. were responsible for the methodology, validation and supervision. F.T., E.T., Z.J., and N.K. were involved in data extraction and analysis. F.T., E.T., and Z.J. prepared the initial draft of the paper, and F.S. and S.N. contributed to the development and refinement of subsequent drafts. All authors read and approved the final manuscript.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
All methods were carried out in accordance with relevant guidelines and regulations in the Declaration of Helsinki. Also, this study was reviewed and approved by the National Ethics Committee of Biomedical Research (IR.IUMS.REC.1402.073). No human participant was involved in this research.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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