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REVIEW

Digital health and COVID-19 response: Scoping review of solutions developed and implemented by BRICS countries

Saúde digital e covid-19: revisão de escopo das soluções desenvolvidas e implementadas pelos países Brics

Nadyelle Elias Santos Alencar[1], Leticia Bastos Conrado[2], Paulo Henrique Leal de Sousa[3], Cláudia Hoirisch[4], Cláudia Alexandra da Cunha Pernencar[5], Luiz Odorico Monteiro de Andrade[6], Ivana Cristina de Holanda Cunha Barreto[6]

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ABSTRACT This study aimed to analyze the state-of-the-art regarding digital health solutions for surveillance, prevention/control, and clinical management of COVID-19 in the BRICS countries. It is a scoping review guided by the Joanna Briggs Institute methodology. Documents published between January 2020 and August 2022 were included from the MEDLINE/PubMed, Lilacs, Scopus, and Web of Science databases, as well as from the websites of the countries' health ministries, the World Health Organization, and the BRICS Summits. In total, 481 documents were included, from which 900 mentions of digital solutions were extracted. Of these, 89% came from databases and 11% from other sources. China led in the number of solutions (47%), followed by India (30%) and Brazil (14%). Most solutions were subnational in coverage (53%) and publicly funded (52%), particularly in Brazil (71%) and Russia (68%). The main technology types were eHealth (72%), big data (32%), and artificial intelligence (30%). There was an emphasis on the use of digital solutions by data services for surveillance and by healthcare professionals for clinical management of COVID-19. The study revealed the main digital solutions developed and implemented by the countries, highlighting similarities and differences, and pointing to cooperation as a path to overcome common challenges.

KEYWORDS Digital health. COVID-19. Pandemics. Review.

RESUMO *Objetivou-se analisar o estado da arte sobre soluções em saúde digital para vigilância, prevenção/controle e manejo clínico da covid-19 nos países do Brics. Revisão de escopo guiada pela metodologia do Instituto Joanna Briggs. Foram incluídos documentos publicados, entre janeiro/2020 e agosto/2022, nas bases Medline/PubMed, Lilacs, Scopus e Web of Science; além dos sites dos Ministérios da Saúde dos países, da Organização Mundial da Saúde e das Cúpulas do Brics. Ao final, foram incluídos 481 documentos, dos quais 900 menções a soluções digitais foram extraídas. Dessas, 89% foram das bases de dados, e 11%, de outras fontes. A China liderou em número de soluções (47%), seguida pela Índia (30%) e pelo Brasil (14%). As soluções foram, em sua maioria, de abrangência subnacional (53%) e de financiamento público (52%), especialmente no Brasil (71%) e na Rússia (68%). Os principais tipos tecnológicos foram eSaúde (72%), mega dados (32%) e inteligência artificial (30%). Houve ênfase no uso de soluções digitais pelos serviços de dados para vigilância e pelos profissionais da saúde para manejo clínico da covid-19. O estudo revelou as principais soluções digitais desenvolvidas e implementadas pelos países, destacando similaridades e diferenças e apontando a cooperação como caminho para superar desafios comuns.*

PALAVRAS-CHAVE *Saúde digital. COVID-19. Pandemias. Revisão.*

[1] Instituto Federal de Educação, Ciência e Tecnologia do Maranhão (IFMA) – Pedreiras (MA), Brasil.
nadyelle.alencar@ifma.edu.br

[2] Universidade Federal do Ceará (UFC) – Fortaleza (CE), Brasil.

[3] Instituto Federal de Educação, Ciência e Tecnologia do Maranhão (IFMA) – Codó (MA), Brasil.

[4] Fundação Oswaldo Cruz (Fiocruz) – Rio de Janeiro (RJ), Brasil.

[5] Instituto Politécnico de Leiria (IPLeiria) – Leiria, Portugal.

[6] Fundação Oswaldo Cruz (Fiocruz) – Eusébio (CE), Brasil.

Introduction

In December 2019, an outbreak of a novel virus emerged in Wuhan, Hubei Province, China[1]. Classified within the coronavirus family, SARS-CoV-2 is the pathogen responsible for causing COVID-19, an infectious disease characterized by a spectrum of clinical manifestations, which can range from asymptomatic cases to severe conditions that necessitate intensive medical care[2].

The rapid transmission and potential severity of the virus led to a swift global spread, with the World Health Organization (WHO) declaring a pandemic in March 2020[3]. By the end of the first year, over 116 million cases and 2.7 million deaths had been reported worldwide. Notably, nearly one-quarter of the total cases (24%) and one-fifth of the deaths (21%) were concentrated in the five countries that comprised the BRICS group at that time: Brazil, Russia, India, China, and South Africa[4].

BRICS represents a significant political and economic group of rapidly developing nations. The group includes nearly half of the world's population. It occupies around 30% of the Earth's land area, positioning it as a significant contributor to both the production and consumption of health supplies. This coalition seeks to identify areas of complementarity, develop solutions for common challenges, and spearhead initiatives at both regional and global levels[5].

The pandemic profoundly impacted the BRICS nations, challenging their capacity to secure sustainable health financing while coordinating with other sectors. In July 2021, the BRICS health ministers advocated for a multilateral approach to address the pandemic threat and enhance collective response capabilities. They also highlighted the pivotal role of Digital Health (DH) in combating the pandemic and endorsed the integration of digital technologies into national health systems[6].

As the first pandemic in a digitally connected era, DH played a crucial role in the implementation of public health measures for COVID-19 surveillance, prevention/control, and clinical management[7]. Conceptually, DH encompasses the application of Information and Communication Technologies (ICT) in healthcare, which includes a wide range of technologies such as eHealth (electronic health), Artificial Intelligence (AI), big data, wearable devices, the Internet of Things (IoT), and robotics[7,8].

An analysis of the pre-pandemic period, spanning from 1999 to 2018, revealed a growing interest in this topic among BRICS countries[9]. However, within the context of COVID-19, there are currently no comparative review studies examining Digital Health Solutions (DHS) across the BRICS group as a whole. Sharing experiences and best practices is a key opportunity to strengthen BRICS health systems and enhance global health.

Given the significance of DH in addressing COVID-19 and the relevance of the BRICS group in global health governance, there is a compelling need to explore the development and implementation of DHS as part of the rapid pandemic response in these nations. Therefore, this study aims to analyze the state-of-the-art regarding DHS for the surveillance, prevention/control, and clinical management of COVID-19, as developed and implemented by the BRICS countries[10].

As part of this broader effort, two complementary articles were produced: the first focusing exclusively on the bibliometric analysis of records retrieved from databases[10], and the second, corresponding to this study, integrating data from both database records and gray literature to provide a comprehensive characterization of the DHS implemented by the BRICS countries.

Material and methods

This is a scoping review, a suitable approach for emerging topics, which enables the reporting of evidence and the identification of knowledge gaps. A distinctive aspect of this method

is its focus on analyzing the state-of-the-art without strict eligibility criteria, enabling the inclusion of diverse evidence and providing a comprehensive understanding of the topic[11].

The methodology for this review followed the Joanna Briggs Institute guidelines and involved five steps: 1) defining the research question, 2) identifying relevant documents, 3) selecting documents, 4) extracting data, and 5) summarizing and presenting the results[11].

Each step was performed by pairs of researchers, with a third reviewer resolving any conflicts that arose. To ensure transparency, the study protocol was registered on the Open Science Framework on October 4, 2022[12].

Step 1: Defining the research question

The general research question, based on the PCC mnemonic (Population, Concept, Context)[11] was: What is the current state-of-the-art regarding DHS for the surveillance, prevention/control, and clinical management of COVID-19 developed and implemented by BRICS countries? The population refers to the BRICS countries in 2022; DHS represents the concept; and the context is the response to COVID-19[10].

The study protocol outlines three specific sub-questions[12]. The first sub-question – How is the field characterized by country, authors and affiliations, source and date of publication, keywords, document type, and study method? – was already addressed by the authors in a previous publication[10]. This article focuses on the remaining two sub-questions: 1) How are DHS for combating COVID-19 in BRICS countries characterized in terms of technology type, focus, target audience, coverage, and funding source? and 2) What are the similarities and differences regarding the DHS developed and implemented to combat COVID-19 across the BRICS countries?

Step 2: Identifying relevant documents

Relevant documents were identified through searches in both health-specific and interdisciplinary databases (MEDLINE/PubMed, Lilacs, Scopus, Web of Science)[10]. Additionally, grey literature was gathered from the following websites: the Ministry of Health (MoH) of Brazil, the MoH of Russia, the Ministry of Health and Family Welfare (MHFW) of India, the National Health Commission (NHC) of China, the National Department of Health (NDH) of South Africa, the WHO, the WHO Digital Health Atlas, and the BRICS Summits (XII to XIV).

The search included documents published up to August 2022. This timeframe is believed to capture the immediate response to COVID-19 and how countries mobilized to incorporate DHS into their emergency response efforts rapidly.

Access to the databases was granted through the Journal Portal of the Coordination for the Improvement of Higher Education Personnel (CAPES), using an Internet Protocol (IP) address provided by the Federal University of Ceará, enabling the retrieval of both open-access and subscription-based materials.

Search expressions were developed based on pre-selected terms, adhering to the specific guidelines for each database. Standardized terms (MeSH Terms) were combined with their synonyms for the same PCC element using the Boolean operator 'OR'. The resulting expressions for each element were then linked with 'AND'. *Table 1* details the search terms and strategy utilized in the MEDLINE/PubMed database, while analogous expressions were created for the other databases.

Table 1. Terms and search strategy for identifying records in the databases

Population	brics; brazil; china; india; russia; south africa
Concept	artificial intelligence; digital technology; biomedical technology; internet of things; mobile applications; social media; technology; remote consultation; telemedicine; wearable electronic devices; technological innovations; connected health; digital health; ehealth; eletronic health; health care technology; health innovations; health technology; mhealth; mobile health; telecare; teleconsultation; telediagnosis; telehealth; virtual healthcare
Context	sars-cov-2; covid-19; 2019 novel coronavirus disease; 2019-ncov; covid-19 pandemic; coronavirus disease 2019
Search on MEDLINE/PubMed: 887 records as of August/2022	("artificial intelligence"[MeSH Terms] OR "digital technology"[MeSH Terms] OR "biomedical technology"[MeSH Terms] OR "internet of things"[MeSH Terms] OR "mobile applications"[MeSH Terms] OR "remote consultation"[MeSH Terms] OR "telemedicine"[MeSH Terms] OR "wearable electronic devices"[MeSH Terms] OR "big data"[MeSH Terms] OR "technological innovations"[Text Word] OR "connected health"[Text Word] OR "digital health"[Text Word] OR "ehealth"[Text Word] OR "eletronic health"[Text Word] OR "health care technology"[Text Word] OR "health innovations"[Text Word] OR "health technology"[Text Word] OR "mhealth"[Text Word] OR "mobile health"[Text Word] OR "telecare"[Text Word] OR "teleconsultation"[Text Word] OR "telediagnosis"[Text Word] OR "telehealth"[Text Word] OR "virtual healthcare"[Text Word]) AND ("sars-cov-2"[MeSH Terms] OR "covid-19"[MeSH Terms] OR "2019-ncov"[Text Word] OR "2019 novel coronavirus disease"[Text Word] OR "coronavirus disease 2019"[Text Word] OR "covid 19 pandemic"[Text Word]) AND ("brics"[Text Word] OR "brazil"[Text Word] OR "russia"[Text Word] OR "india"[Text Word] OR "china"[Text Word] OR "south africa"[Text Word])

Source: Prepared by the authors.

The search for grey literature, or non-academic sources, was adapted to the specific features of the included websites. In this context, relevant publications and other documents addressing the research questions were identified based on the previously outlined search terms.

Step 3: Selecting documents

Online tools were used to automatically remove duplicates (EndNote)[13] and facilitate screening (Rayyan)[14]. Eligibility criteria were applied in two stages: first, documents were assessed based on their title and abstract; then, the selected records were reviewed in full for a final decision.

Records were included if they: 1) referred to at least one BRICS country in 2022 (Brazil, Russia, India, China, or South Africa); 2) presented a DHS (product or service) aimed at persons, healthcare providers, healthcare managers, or data services, as per the WHO's classification of DH interventions[15]; and 3) focused on surveillance (data collection, analysis, and interpretation regarding disease and its determinants), prevention/control (actions and programs to prevent or reduce disease occurrence at individual and collective levels), and/or clinical management of COVID-19 (multidisciplinary care from suspicion to discharge)[10].

Exclusion criteria were: 1) lack of country specification or references to special territories of China (Hong Kong, Taiwan, Macau); 2) absence of a DHS of one of the following types: eHealth (including mobile health – mHealth), AI, health big data, wearable devices, IoT, or robotics; 3) insufficient information to describe the solution and characterize its type, focus, and target population. The same criteria were applied to the selection from the grey literature[10].

Step 4: Extracting data

Using a spreadsheet, data were collected to characterize the documents and the DHS. For this paper, the following aspects were considered: title, publication date (month and year), document type (original journal article, original conference paper, review study, chapter/book, other documents, web pages), country (Brazil, Russia, India, China, South Africa), coverage (subnational, national, or international), funding source (public, private, public-private), type of technology (eHealth, health big data, AI, wearable devices, IoT, robotics), target audience (persons, healthcare providers, healthcare managers, data services), focus (surveillance, prevention/control, and clinical management), and solution description.

Step 5: summarizing and presenting the results

Initially, the final records (from databases and grey literature) were characterized in terms of document type and publication date. As mentioned earlier, a comprehensive bibliometric analysis of documents from the databases has been published in a previous work. It is available in the Journal of Health Informatics, as part of the proceedings of the XX Brazilian Congress on Health Informatics – CBIS'24[10].

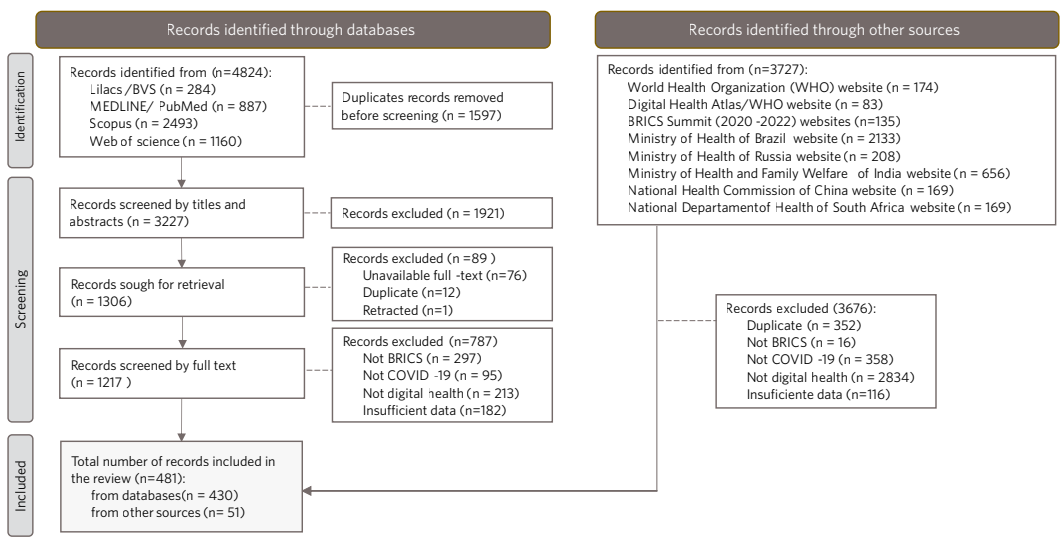
Subsequently, the DHS were characterized by country, coverage, funding, type of technology, focus, and target audience. The data was analyzed for both the BRICS group as a whole and each country to identify similarities and differences.

For the descriptive analysis, absolute and relative frequencies were calculated. The data analysis was performed using the statistical software R, and the figures were generated with Tableau version 2024.2.

Results

A total of 8,551 records were retrieved, with 481 included in the final sample after screening (89% from databases and 11% from other sources). The complete PRISMA workflow is shown in *figure 1*.

Figure 1. PRISMA flowchart of procedures used in the identification of records through databases and other sources



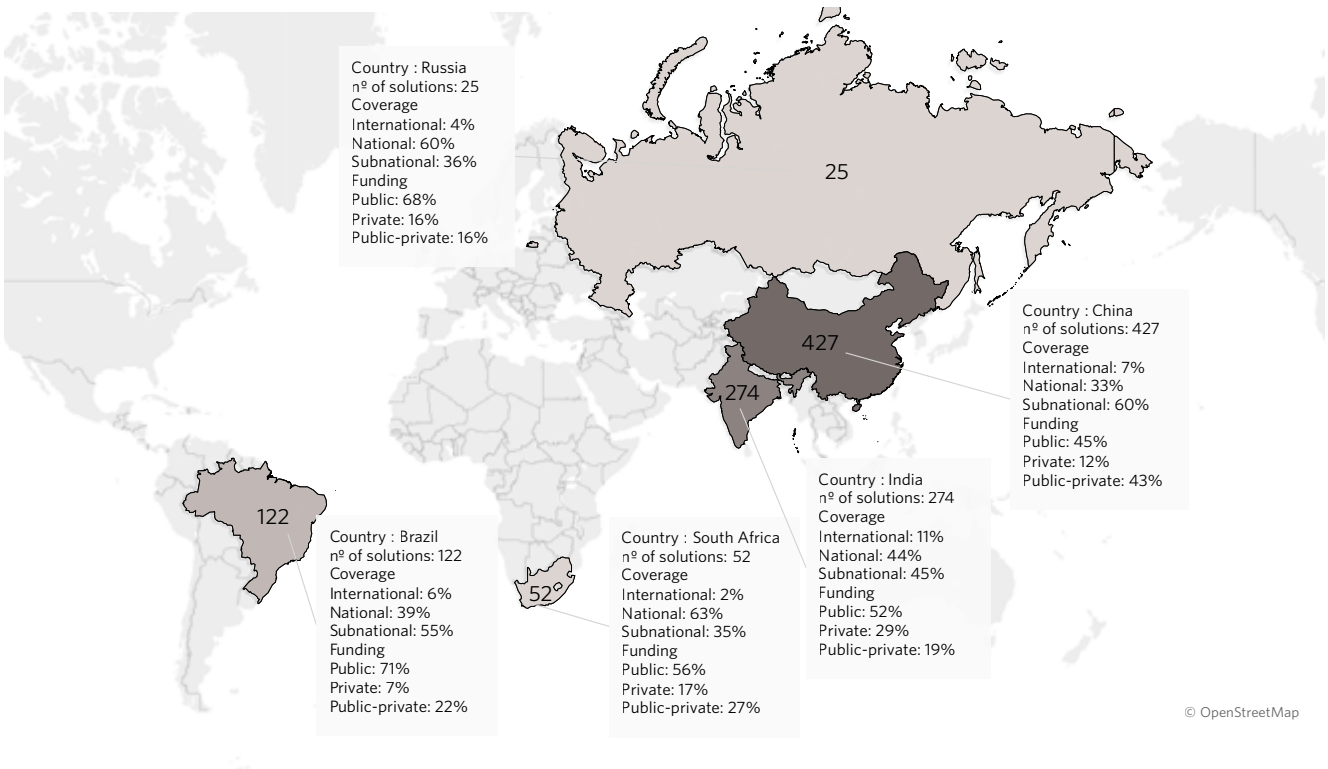
Source: Prepared by the authors.

The analyzed period spanned from January 2020 to August 2022. The temporal distribution of the records revealed a peak in publications during the first half of 2021, with 135 records (28%), followed by a decrease of approximately 53% during the same period in 2022.

Regarding the types of records, the most frequent were original journal articles (56%). These were followed by other documents (14%), including editorials, letters to the editor, comments, opinions, reports, and more. Conference papers (12%), internet web pages (9%), review studies (6%), and book chapters (3%) were less frequent.

Notably, each record could mention one or more DHS. From the 481 included records, 900 mentions of DHS developed and implemented by BRICS countries to combat COVID-19 were identified. *Figure 2* presents the distribution of solutions by country, with darker shades indicating a higher number of initiatives. China led with 47%, followed by India (30%) and Brazil (14%). Only one DHS resulted from the partnership between BRICS countries, specifically between India and South Africa, highlighting the low level of intra-BRICS cooperation.

Figure 2. Number, coverage, and funding of the digital health solutions for combating COVID-19 in BRICS countries, from January 2020 to August 2022



Source: Prepared by the authors.

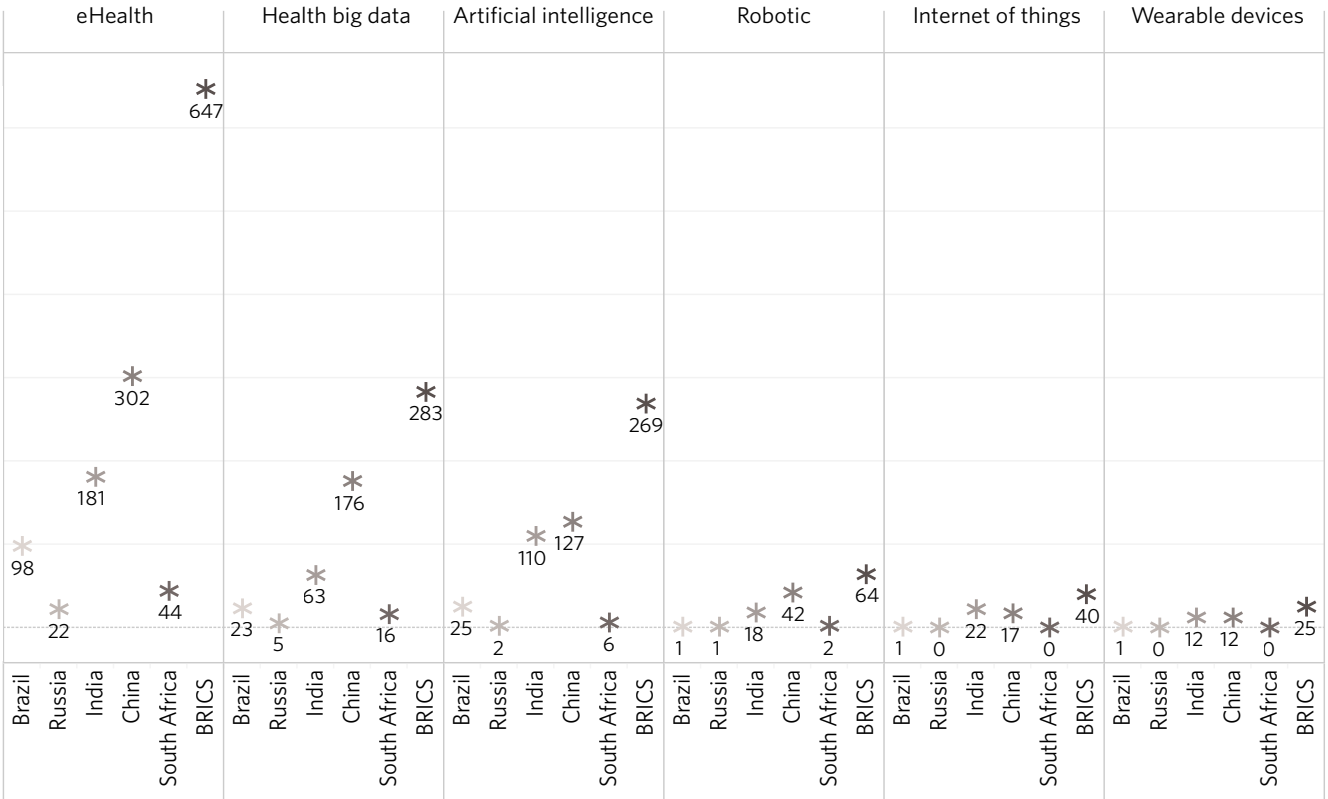
Among the analyzed solutions, 53% had subnational coverage (limited to part of the country), 40% had national coverage (spanning the entire country), and 7% had international coverage (extending beyond one country). China and Brazil stood out for their

predominance of subnational solutions, with 60% and 55%, respectively. South Africa and Russia had a higher proportion of national solutions, at 63% and 60%, respectively. In India, national and subnational solutions were balanced, together accounting for 89% of the country's total, with India also having the highest proportion of international solutions, at 11%.

Public funding emerged as the most common source of financing, accounting for 52% of the total, with particularly high levels in Brazil (71%) and Russia (68%). Public-private partnerships followed as the second most prevalent source (31%), notably higher in China (43%) and South Africa (27%). Involvement from the private sector was the least frequent, representing 17%, but was most significant in India (29%) and South Africa (17%).

Regarding the types of technologies, *figure 3* illustrates the most prevalent ones within the BRICS group and their distribution by country. The main types of technology in the group were eHealth (72%), health big data (32%), and AI (30%). An analysis of individual countries revealed similar trends, highlighting the development and implementation of these three technology types across all five countries examined.

Figure 3. Digital health solutions for combating COVID-19 in BRICS countries in terms of type of technology, from January 2020 to August 2022



Source: Prepared by the authors.

Figure 4 displays the distribution of DHS according to focus and target audience, encompassing both the BRICS group as a whole and each country. The most frequent classifications are indicated in darker shades.

Figure 4. Digital health solutions for combating COVID-19 in BRICS countries in terms of focus and target audience, from January 2020 to August 2022

		Target audience				
Country	Focus	Persons	Healthcare providers	Healthcare managers	Data services	Total
Brazil	Surveillance	6%	7%	2%	12%	28%
	Prevention and Control	8%	9%	2%	6%	25%
	Clinical management	12%	20%	3%	12%	47%
	Total	27%	36%	7%	30%	100%
Russia	Surveillance	9%	8%	3%	10%	29%
	Prevention and Control	12%	11%	2%	6%	31%
	Clinical management	9%	16%	3%	12%	40%
	Total	29%	34%	9%	28%	100%
India	Surveillance	9%	10%	1%	13%	33%
	Prevention and Control	11%	10%	2%	9%	32%
	Clinical management	9%	14%	2%	11%	35%
	Total	29%	34%	4%	33%	100%
China	Surveillance	9%	10%	5%	13%	38%
	Prevention and Control	10%	11%	5%	10%	36%
	Clinical management	6%	11%	1%	8%	26%
	Total	25%	32%	12%	31%	100%
South Africa	Surveillance	8%	10%	4%	11%	34%
	Prevention and Control	11%	11%	4%	10%	36%
	Clinical management	7%	12%	3%	8%	30%
	Total	26%	33%	11%	30%	100%
BRICS	Surveillance	9%	10%	3%	13%	35%
	Prevention and Control	10%	11%	4%	9%	34%
	Clinical management	8%	13%	2%	9%	32%
	Total	26%	33%	9%	31%	100%

Source: Prepared by the authors.

In Brazil, clinical management was the focus of the majority of DHS (47%), with healthcare providers being the most frequent target audience (36%). Remarkably, solutions targeting healthcare providers and focused on the clinical management of COVID-19 accounted for 20% of the total.

Similarly, in Russia, clinical management was the most common focus (40%), and healthcare providers represented the most significant target audience (34%). Therefore, solutions targeting healthcare providers and emphasizing the clinical management of COVID-19 also played a significant role in Russia, representing 16%.

In India, the focuses were relatively balanced, with clinical management (35%) and surveillance (33%) standing out as slightly more frequent. The primary target audiences consisted of healthcare providers (34%) and data services (33%). Notably, healthcare providers utilized solutions for clinical management at a rate of 14%, while data services employed solutions for COVID-19 surveillance at a rate of 13%.

In China, the key focuses were surveillance (38%) and prevention/control (36%). The most common target audiences included healthcare providers (32%) and data services (31%). Distinguished solutions comprised those

directed at data services focusing on surveillance (13%), as well as those targeting healthcare providers for prevention/control (11%) and clinical management of COVID-19 (11%).

In South Africa, the primary focuses were prevention/control (36%) and surveillance (34%), while the most prevalent target audiences included healthcare providers (33%) and data services (30%). Notably, the most significant solutions were those directed at healthcare providers, emphasizing clinical management (12%) and prevention/control (11%), as well as those aimed at data services concentrating on surveillance (11%).

Considering the BRICS group as a whole, DHS were distributed evenly across the three focus categories. Regarding the target audience, healthcare providers (33%) and data services (31%) were the most frequently addressed categories, while healthcare managers represented the least at 9%. The BRICS group emphasized the development and implementation of DHS aimed at data services, with a focus on COVID-19 surveillance (13%) and those directed at healthcare providers, focusing on the clinical management of COVID-19 (13%).

Discussion

This study investigates the DHS developed and implemented by BRICS countries in response to COVID-19. The analysis begins with a synthesis of the main findings, followed by three sections that present the DHS across three key focus areas: surveillance, prevention/control, and clinical management.

DH played a crucial role in addressing COVID-19 across the BRICS countries. Since 2020, the number of DHS has grown exponentially within the group, reaching its peak in 2021, followed by a subsequent decline. This phenomenon reflects Gartner's hype cycle, where, after a peak of inflated expectations, a phase of disillusionment emerges due to practical challenges. In the post-pandemic context, effective technologies are expected to overcome these obstacles and consolidate, integrating sustainably into health systems[16].

For this integration to succeed, a coordinated effort among various stakeholders is essential, with governments and public health policymakers playing a leadership role[17]. As pointed out in this review, the DHS deployed to address COVID-19 in the BRICS countries were predominantly funded by the public sector and at a subnational level, especially in Brazil, followed by China.

The COVID-19 pandemic tested the resilience of Brazil's Unified Health System (SUS). The challenges faced by SUS became evident as states and municipalities encountered disarticulation with the federal government, exacerbated by a series of denialist and misguided measures, including frequent changes in health ministers, the weakening of primary health, the imminent threat of healthcare system collapse, and instances of corruption in vaccine procurement and distribution[18]. These issues compromised the MoH's ability to coordinate the pandemic response effectively. Nevertheless, the decentralized structure and broad reach of SUS enabled state and municipal health departments to develop solutions at the subnational level.

Public-private partnerships have also proven essential for overcoming the challenges of traditional centralized public administration, ensuring a more effective and inclusive response. Local governments play a key role in establishing regulations that foster collective action and collaboration, enabling the delivery of quality public services, especially during crises like the COVID-19 pandemic[19].

In China, where public-private collaboration was most prevalent within the group, national policy guidelines actively promoted private sector participation. This facilitated the development and implementation of DHS in priority areas while allowing adjustments based on each region's unique conditions. While this approach stimulated innovation, it also exacerbated inequalities in infrastructure and regional capabilities[20].

Overall, developing countries consider digitization as a means to expand access to and improve the quality of health services provided to their populations. However, several technical and legal barriers, ranging from infrastructure limitations and interoperability issues to inadequate data security measures and regulatory complexities, hinder the potential for transformative changes in healthcare within these regions[17].

It is important to emphasize that technologies should not be perceived as a universal solution to health challenges; in some cases, they may even worsen existing issues, as seen in India. With the private sector dominating health service delivery and technology provision, digitization does not ensure equitable benefits for all, leaving a significant portion of the population without access[21]. While India has generated the second-highest amount of evidence on DHS to combat COVID-19, concerns persist regarding the reach and equity of access to the benefits provided by these solutions.

Regarding the number of solutions identified, China ranked first among BRICS countries, reflecting its established leadership in the field of medical informatics prior to the pandemic. The findings of this research align with a bibliometric analysis of publications from 1999 to 2018, which identified China as the primary reference for the number of publications within the group, followed by India and Brazil. Furthermore, eHealth, particularly mHealth, has been recognized as the most significant research area among BRICS countries[9].

eHealth encompasses subdomains such as telehealth, mHealth, and health information technology. These solutions leverage digital technologies to enhance access to and the quality of healthcare, including online consultations, remote diagnostic support, and the development of digital infrastructure such as electronic health records and information systems. Such services have been essential for the surveillance, prevention/control, and clinical management of COVID-19[22].

A new aspect observed was the growing interest of BRICS countries in health big data and AI. Big data is characterized by five main attributes, known as the 5 V's: volume (large amount), variety (diverse types), velocity (rapid generation and processing), value (low value per data point), and veracity (reliability)[23]. In turn, AI refers to the ability of machines or software to perform tasks that typically require human intelligence, such as learning, pattern recognition, and decision-making. These two technologies played a crucial role in combating COVID-19, with applications ranging from tracking and predicting outbreaks to supporting diagnosis and treatment[24].

Additionally, the limited intra-BRICS cooperation is a key point for discussion. The group holds significant potential to influence international health issues, propose solutions for shared challenges, and lead initiatives targeting the Global South. However, advancing cooperation faces obstacles such as geopolitical tensions between Russia and China, competition in the pharmaceutical market between China and India, and shifts in Brazil's foreign policy, all of which threaten the group's cohesion[5].

The analysis revealed that the DHS, which was developed and implemented to address COVID-19, lacked effective coordination among the BRICS nations. Therefore, it is crucial to examine the results considering each nation's specific characteristics, and to emphasize both similarities and differences. Notable similarities were found in the types of technologies most frequently used across the nations. Furthermore, countries with a strong state presence in healthcare exhibited higher levels of public funding for DHS.

In this context, public funding for DHS was notably more prevalent in Brazil and Russia, where government health spending accounts for 45% and 71% of total health spending, respectively. Conversely, private funding for DHS was more common in India, where out-of-pocket spending by patients comprises 50%

of total health spending, and in South Africa, where voluntary prepayments cover 32% of total health spending[25].

Two additional aspects warrant attention. First, the encouragement of public-private partnerships significantly expanded the scope of DHS in China[20]. Second, India holds a prominent position in the realm of international DHS. Within the BRICS, a group focused on cooperation for global development[5], embracing an international perspective on health issues can foster innovative and alternative approaches that differ from traditional practices typically led by developed nations.

Next, the primary DHS developed and implemented to address COVID-19 in the BRICS countries will be presented, organized according to their main focus area: surveillance, prevention/control, and clinical management.

Digital health solutions for COVID-19 surveillance in BRICS countries

In response to the threat posed by a new virus with no proven vaccines or scientifically validated treatments, surveillance emerged as a critical measure to mitigate the impact of the pandemic[3]. Various DHS were employed to monitor the disease and its determinants, including data collection and analysis to generate crucial information for public management.

A relevant example is the solutions for monitoring population flow. In India, case tracking and contact notification were conducted through the Aarogya Setu app, which means bridge to health. This government-mandated solution became the fastest-growing mobile tracking application in the world, achieving 50 million downloads in under two weeks following its launch. Widely used across the country, the app operated based on location and Bluetooth data[26].

In China, the Health QR Code adopted an innovative approach by utilizing big data technology to classify users into a three-color system, similar to a traffic light: yellow and red indicated quarantine for seven to 14 days, while green allowed free movement. Integrated into national platforms like Alipay (Alibaba) and WeChat (Tencent) through a mini-app, the classification was based on self-reported symptoms, travel history, epidemiological data, and geolocation. Updated daily, the code was required for routine activities and played a key role in the economic reopening process[20].

In Moscow, the capital of Russia, the Social Monitoring app was used for the mandatory tracking of COVID-19 patients or suspected cases in home quarantine, employing geolocation. The app monitored users' locations, and to enforce isolation measures, it introduced a controversial feature to prevent them from leaving their phones at home. Users were required to take selfies as proof of isolation, which raised concerns about data security and the legality of processing biometric information[27].

In contrast to previously successful initiatives, the COVIDAlert SA app in South Africa and the Coronavirus-SUS app in Brazil did not yield the expected results. In South Africa, low adoption rates were attributed to concerns over privacy and data security, which fostered distrust in the government initiative[28]. In Brazil, the Coronavirus-SUS app encountered challenges not only due to low visibility but also because of technical difficulties related to its dependence on a tracking system developed in collaboration with Google and Apple. This reliance resulted in restrictions concerning privacy policies for data access and required users to have updated Android or iOS smartphones[29]. Furthermore, the voluntary nature of application usage in both countries contributed to low engagement, which limited the effectiveness of the tools.

Other surveillance solutions employed robotics, including unmanned aerial monitoring with multifunctional drones deployed in various cities across China and India. These drones were equipped with cameras to monitor crowds and provide instructions to individuals who were not adhering to government guidelines. Some models also integrated

AI for facial recognition of those violating the measures, while others enabled large-scale temperature measurement through infrared cameras[30].

Moreover, data management proved to be an invaluable solution for tracking COVID-19 trends in these countries. Data visualization systems, also known as dashboards, were created to present real-time information about the pandemic, including the count of cases, deaths, hospitalizations, testing, and vaccinations. These dashboards not only assisted managers and professionals in planning and making strategic decisions but also fostered transparency in communication with the public[31,32].

Besides data visualization, China distinguished itself through its sophisticated approach to big data analysis. The government integrated data from multiple sources, including mobile telecommunications, payment systems, travel records, and video surveillance, to trace the life paths of infected individuals and monitor their contacts. Additionally, the incorporation of AI algorithms facilitated efficient data mining, comprehensive monitoring, and the provision of early warnings regarding potential outbreaks[33].

Overall, applications for monitoring population flow and dashboards for data monitoring were commonly utilized across the countries. In contrast, robotics for surveillance was particularly prominent in China and India, while the integration of big data with AI set China apart. It is evident that the system of governance, technical capabilities, outreach strategies, and population engagement shaped National experiences.

COVID-19 surveillance in BRICS countries employed a twofold strategy, encompassing both comprehensive and specific elements. It provided a thorough integration of data that allowed professionals and managers to grasp the overall landscape and make future projections related to the health crisis. At the same time, it focused on utilizing tools specifically designed to identify and monitor individuals according to their exposure to the virus. These measures informed both individual and collective actions for the prevention/control of COVID-19 in these countries, which will be elaborated upon below.

Digital health solutions for COVID-19 prevention/control in BRICS countries

Allied with surveillance efforts, the prevention/control of new cases was essential to curbing the exponential spread of the pandemic and preventing the overburdening of health services[3]. In this context, governments adopted measures to enhance public engagement and cooperation. They developed various strategies to disseminate information, address concerns, and combat misinformation through DH initiatives. Nationally, official health authority websites and the government's presence on social media brought public administration closer to the population.

In addition to official health authority websites, countries developed and implemented other DHS such as virtual assistants and mobile applications. In Brazil, for example, a chatbot (a computer program that simulates conversations with humans) available on the MoH website and the Coronavírus-SUS app were both used to raise awareness about the disease, although they saw limited adoption. About a year after its launch, the app had been downloaded by fewer than 5% of the country's population[34].

Chatbots were also used in Russia to disseminate information, operating through the MoH website and instant messaging platforms such as ICQ and WhatsApp[35-37]. In South Africa, HealthAlert was another example of a chatbot that operated on WhatsApp[38]. In India, a chatbot was integrated into MyGov, the world's largest platform for citizen-government engagement. Launched in partnership with Amplify.ai, the conversational AI solution allowed citizens to ask questions and clarify doubts about COVID-19[39].

In China, in addition to prioritizing public information, the government took significant steps to combat misinformation. The People's Daily, one of the most influential newspapers and the official organ of the Communist Party of China, played a vital role in disseminating COVID-19 information through its WeChat account, the country's most popular social media platform[40]. Additionally, collaboration between the government and technology companies led to the implementation of anti-misinformation measures, such as tagging, fact-checking, and the removal of false or outdated content, all aimed at preventing widespread panic among citizens[41].

Vaccination management was also a central focus of DHS across the countries. In Brazil, the Conecte SUS application, renamed Meu SUS Digital in January 2024, organized the ecosystem of healthcare services and COVID-19-related data through the National Health Data Network (RNDS). Since March 2021, the app has enabled citizens to access their digital vaccination card, which includes records of administered doses and their national immunization certificate. It is expected to become the primary access point for health data in the country[34].

Similarly, in Russia, the Public Services Portal incorporated a special COVID-19 section that allowed users to schedule vaccination appointments and obtain immunization certificates[42]. In India, the vaccination process was managed through the CoWIN portal, which centralized the organization, planning, execution, and monitoring of vaccination efforts. Interestingly, the system registered individuals seeking vaccination at both public and private facilities. Although vaccination is recognized as a right, those who could afford it were encouraged to seek immunization through the private sector, where a fee was charged for the service[43].

In South Africa, the FindMyJab platform helped citizens locate vaccination sites[44], while the Coronavirus Electronic Vaccination Data System (EVDS) was used for appointment scheduling, involving both the public and private sectors, similar to India[45]. In China, updated information on vaccination sites and procedures was provided through widely used national and subnational apps[46]. A noteworthy aspect of this strategy was the integration of multiple services and features into existing applications, which facilitated user engagement.

Another significant solution was the use of big data and AI in the development of vaccines and drugs against COVID-19[24]. In China, internet companies like Tencent partnered with national research centers to create a platform for developing vaccines and treatments. Utilizing advanced computing resources, the platform supported large-scale epidemiological research[23].

In summary, DHS for COVID-19 prevention/control prioritized information dissemination and communication to foster public engagement. In China, particular emphasis was placed on media control and combating misinformation. Vaccination processes were also prioritized, with countries like Brazil focusing on managing immunization certificates. In contrast, others, such as India, implemented broader strategies encompassing the planning, execution, and monitoring of vaccination campaigns. Additionally, China enhanced user experience by integrating new features into existing apps instead of developing new ones. Moreover, the use of big data and AI further accelerated the development of vaccines and medicines. The discussion will now turn to the role of DHS in the clinical management of COVID-19.

Digital health solutions for COVID-19 clinical management in BRICS countries

COVID-19 spread rapidly and achieved pandemic status due to its high transmissibility and the significant increase in global cases[3].

While approximately 80% of patients experience mild to moderate symptoms, disease progression can lead to severe respiratory failure. About 5% of symptomatic cases develop into critical conditions that require intensive care[2].

The initial challenges in managing COVID-19 included a lack of knowledge about the new virus, the absence of proven effective drug therapies, early vaccine access by developed countries, shortages of supplies, the spread of misinformation, and widespread panic, which resulted in overcrowding in health services. In this context, there was a pressing need to diversify health service delivery modalities, with telehealth playing a crucial role in addressing these issues[47,48].

The provision of remote care was relevant in addressing COVID-19 in BRICS countries. In Brazil, telemedicine was regulated on an emergency basis during the pandemic, marking the first time its practice was authorized across all health sector activities, including teleconsultation[49]. National initiatives such as TeleSUS provided pre-clinical telecare to prevent overwhelming health units. Another significant solution was TeleUTI, which employed telemedicine to connect teams from smaller hospitals to larger centers through teleconferencing[34].

In Russia, telemedicine centers were established at both federal and regional levels to provide remote patient counseling and support for healthcare providers[50]. However, there are perceived barriers to equitable access to these services, particularly for specific groups such as residents of rural areas, older adults, and individuals with low education and socioeconomic vulnerability[51]. Moreover, legislation in the country imposes several restrictions on telemedicine practice, permitting health monitoring and minor therapeutic adjustments but prohibiting diagnoses and the initiation of new therapies via remote technologies[52].

Additionally, the Public Services Portal of the Russian Federation incorporated a special feature for the daily registration of key health parameters. This information was transmitted to the citizen's federal entity of residence, enabling timely monitoring, guidance, and referrals. However, more detailed information about the implementation and effectiveness of this solution was not made available[53].

In India, the eSanjeevani platform, developed by the government, became the world's fastest-growing mobile app focused on clinical management, facilitating approximately 3 million free consultations in its first year of the pandemic[54]. In the private sector, most major hospitals adopted innovations in telemedicine and began offering virtual services. To address disparities in access to these technologies, some hospitals and startups launched the national telemedicine platform, Swasth, which provided low-cost care for low-income populations. Furthermore, the StepOne project enabled consultations through an automated voice system, allowing individuals without smartphones or internet access to connect via phone calls[55].

In China, DH initiatives led by internet companies, public hospitals, and regional governments alleviated pressure on in-person services and reduced the risk of cross-infection. Internet Hospitals played a crucial role in facilitating communication between doctors and patients, providing care, and offering smart triage and remote follow-up[56]. In addition, a national telemedicine center was established to offer professional support, enabling specialists to guide other doctors in managing severe and critical COVID-19 patients[57].

In South Africa, the government provided free medical consultations through the Hello Doctor platform, which helped address the shortage of professionals in certain regions and the need for more accessible care[58]. Other solutions, including Vula Mobile, Signapps, and DrConnect, were also implemented in the country. Vula Mobile facilitated connections between frontline professionals and specialists, while Signapps and DrConnect offered teleconsultation and remote monitoring services. However, these solutions encountered challenges related to intermittent internet connectivity and

inadequate infrastructure, along with data security and privacy issues[59].

Robotics also enhanced healthcare routines in China and India. In Chinese hospitals, smart robots were utilized to assist healthcare providers with patients' daily needs by performing simple tasks such as delivering medications and food, thereby reducing the risk of infection[57,58]. Similarly, in India, robotic solutions served multiple functions, including supply delivery, vital signs monitoring, waste collection, and the disinfection of isolation wards and common areas. In addition, these robots facilitated video calls between patients and doctors or family members[39].

For real-time monitoring of patients while minimizing human contact, wearable devices were utilized[58]. Moreover, integrating devices such as smart rings and bracelets with IoT enabled the wireless transmission of patient data – such as temperature, heart rate, and oxygen saturation – directly to the healthcare team. These technologies significantly reduced the risk of infection for healthcare professionals and alleviated the workload in hospitals[30]. Such solutions were predominantly adopted in China and India.

Other solutions aimed at professionals provided diagnostic support. Given the shortage of diagnostic tests, alternatives were developed to assist in identifying patients with the disease using AI technology. AI models were trained using a variety of data sources, including chest imaging[60], cough sounds[61], clinical and laboratory characteristics[62], as well as other health parameters such as oxygen saturation, blood pressure, and body temperature[63].

Solutions for healthcare managers were also identified, although less frequently. According to the WHO classification, these solutions involve the administration and supervision of health systems, encompassing functions such as supply chain management, health system financial management, and human resources management[15].

In China, for example, a system was proposed to provide information on the supply and demand of resources, facilitating the coordination of medical supplies and ensuring that the needs of different localities were met efficiently[64]. In the state of Kerala, India, a similar solution was proposed to monitor the prices and availability of medical supplies[32]. In Brazil, systems aimed at human resources management focused on the recruitment and registration of healthcare professionals[65].

In summary, DHS played a crucial role in the clinical management of COVID-19, enabling an agile and adaptive response to the global crisis. Central to this discussion, telehealth played a vital role in alleviating the burden on health services, enhancing access, and providing remote support to citizens. Additionally, the use of robotics, wearable devices, and IoT was relevant in China and India. The main challenges identified include a lack of regulation, technological dependence, internet connectivity, data security, and regional and economic disparities.

Conclusions

This study analyzed DHS for the surveillance, prevention/control, and clinical management of COVID-19 in BRICS countries. The solutions developed and implemented reflected the national and subnational priorities and capacities of these nations, with China, followed by India, standing out for its superior production and technological density in the field. The exchange of experiences can significantly enhance the development of DH across countries, while also advancing the health agenda in the Global South, fostering greater cohesion and global relevance within the group.

Similarities were observed in the predominance of eHealth solutions for addressing the new virus. Additionally, big data and AI emerged as significant technologies within the group. For surveillance, monitoring

applications and dashboards were standard tools. In terms of prevention/control, solutions focused on information dissemination and vaccination management were particularly prominent. For clinical management, telehealth played a crucial role, highlighting the importance of technological innovation while also underscoring challenges such as regulation, data security, and regional disparities.

The findings highlight both the diversity and convergence in the digital responses of BRICS countries to the pandemic. The distinct challenges faced by each country, coupled with limited cooperation within BRICS, present opportunities for mutual learning. China's leadership, followed by India, could pave the way for future collaboration, facilitating technology sharing and promoting a collective approach to address common challenges. This cooperation may also better prepare the group for future health emergencies.

Collaborators

Alencar NES (0000-0002-5602-7339)* and Conrado LB (0000-0001-8108-2199)* contributed to project conception, data collection, analysis and interpretation, drafting and approval of the final version of the manuscript. Sousa PHL (0000-0003-3268-2416)* contributed to data collection, analysis and interpretation, drafting and approval of the final version of the manuscript. Hoirisch C (0009-0002-6357-8961)*, Pernencar CAC (0000-0001-8981-2133)*, and Andrade LOM (0000-0002-3335-0619)* contributed to critical revision of intellectual content, and approval of the final version of the manuscript. Barreto ICHC (0000-0001-8447-3654)* contributed to project conception, data analysis and interpretation, critical revision of intellectual content, and approval of the final version of the manuscript. ■

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*Orcid (Open Researcher and Contributor ID).

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