

Study of immunization technologies: a theoretical-practical reflection

Estudio de las tecnologías de inmunización: una reflexión teórico-práctica

Estudo das tecnologias em imunização: uma reflexão teórico-prática

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Abstract

This study aimed to reflect on the need for and potential of developing mobile applications for immunization care management, considering the challenges associated with paper-based vaccination records and the demand for secure, interoperable record-keeping. It is a descriptive, critical reflection study based on an analysis of publications and official documents. A Google Scholar search using the keywords "technology AND immunization" yielded 13,001 publications, of which 39 were included after applying exclusion criteria. Three categories were identified: the history of the National Immunization Program (PNI), vaccination records, and health information technologies. While the PNI stands out as a significant public health intervention, paper-based records have limitations regarding data degradation and loss, potentially leading to unnecessary revaccination or reduced vaccination coverage. Information and communication technologies emerge as an alternative to overcome these issues. The study concludes that developing mobile applications for immunization is a pressing need that can benefit professionals, administrators, and users by reducing costs and risks. Further research on virtual care and public behavior regarding these tools is essential to inform future implementations.

Descriptors: Mobile Applications; Immunization; Vaccination Card; Information and Communication Technologies; National Immunization Program.

Resumen

Este estudio tuvo como objetivo reflexionar sobre la necesidad y el potencial del desarrollo de aplicaciones móviles para la gestión de la atención de inmunización, considerando los desafíos de los registros de vacunación en papel y las exigencias de registros seguros e interoperables. Se trata de un estudio descriptivo y de reflexión crítica basado en el análisis de publicaciones y documentos oficiales. Una búsqueda en Google Scholar con los descriptores "tecnología Y inmunización" arrojó 13.001 publicaciones, de las cuales 39 se incluyeron tras aplicar los criterios de exclusión. Se identificaron tres categorías: historia del Programa Nacional de Inmunización (PNI), registros de vacunación y tecnologías de la información en salud. El PNI se destaca como una intervención relevante de salud pública, pero los registros de vacunación en papel presentan limitaciones en cuanto a la degradación y pérdida de datos, lo que puede conducir a revacunaciones innecesarias o a una disminución de la cobertura de vacunación. Las tecnologías de la información y la comunicación surgen como una alternativa para superar estos problemas. Se concluye que el desarrollo de aplicaciones móviles para la inmunización es una necesidad apremiante, capaz de beneficiar a profesionales, gestores y usuarios, reduciendo costos y riesgos. Es fundamental realizar nuevas investigaciones sobre la atención virtual y el comportamiento público en relación con estas herramientas para respaldar futuras implementaciones.

Descriptores: Aplicaciones Móviles; Inmunización; Cartilla de Vacunación; Tecnologías de la Información y la Comunicación; Programa Nacional de Inmunizaciones.

Resumo

Objetivou-se refletir sobre a necessidade e as potencialidades do desenvolvimento de aplicativos móveis para a gestão do cuidado em imunização, considerando os desafios da caderneta de papel e as demandas por registro seguro e interoperável. Trata-se de estudo de reflexão, descritivo e crítico, baseado em análise de publicações e documentos oficiais. A busca no Google Acadêmico com os descritores "tecnologia AND imunização" resultou em 13.001 publicações, das quais 39 foram incluídas após critérios de exclusão. Identificaram-se três categorias: histórico do Programa Nacional de Imunizações (PNI), caderneta de vacinação e tecnologias da informação em saúde. O PNI destaca-se como relevante intervenção em saúde pública, mas a caderneta de papel apresenta limitações quanto à degradação e perda de dados, podendo levar à revacinação desnecessária ou à queda da cobertura vacinal. As tecnologias da informação e comunicação surgem como alternativa para superar esses problemas. Conclui-se que o desenvolvimento de aplicativos móveis para imunização é uma necessidade premente, capaz de beneficiar profissionais, gestores e usuários, reduzindo custos e riscos. Novas pesquisas sobre cuidado virtual e comportamento do público frente a essas ferramentas são fundamentais para subsidiar futuras implementações.

Descritores: Aplicativos Móveis; Imunização; Caderneta de Vacinação; Tecnologias da Informação e Comunicação; Programa Nacional de Imunizações.



Introduction

In recent decades, the development of digital information and communication technologies has enabled access to data that was previously scarce, allowing healthcare professionals and clients to experience a new form of health education and care: digital care. During this same period, advancements in technologies related to the development, storage, distribution, and tabulation of data on vaccines, serums, and immunizations have contributed to improving the general population's health status. Given that human care can be managed through digital channels, and that healthcare professionals should seek ways to create technologies rather than merely consuming them, the primary objective of this dissertation was to present a mobile application model designed to assist professionals, administrators, and patients/clients with immunization activities. Furthermore, the widespread use of mobile devices (such as smartphones and tablets), combined with the proliferation of wireless Internet access points, creates a favorable environment for mobile applications that help individuals maintain vaccination records in formats other than paper, while also contributing to government monitoring and statistical data¹.

It is now well established that computerized immunization systems are highly useful and offer a high level of sensitivity regarding the safety of all those involved. Immunization is a key component of preventive health measures, with vaccination being the most effective way to prevent various vaccine-preventable diseases, such as smallpox (eradicated), polio, measles, tuberculosis, rubella, influenza, hepatitis B, and yellow fever, among others². It is estimated that 2 to 3 million deaths are prevented annually through vaccination; immunization is one of the most cost-effective health investments for nations, as it enables excellent prevention outcomes at a low cost, especially in countries lacking adequate facilities for disease diagnosis and treatment³.

Vaccinating children during their first year of life is crucial for preventing various diseases and is associated with a reduction in infant mortality rates; identifying vaccination coverage and the factors responsible for delays or missed immunizations is essential for the proper monitoring of vaccination programs⁴. This data is recorded and stored in vaccination booklets, a method still widely used to track vaccination status, the use of which is justified by the fact that they consolidate data relevant to an individual's clinical assessment, such as test results, biometric measurements, and records of consultations and vaccinations, while also providing information and guidance of interest to the target population⁵.

Over time, the vaccination record book has changed to include specific information for certain groups, such as health record books for children, adolescents, pregnant women, and the elderly⁶. However, because they rely on paper as the medium for information, these booklets are susceptible to degradation caused by physical and chemical agents, such as constant handling, improper storage, the passage of time, humidity, and excessive light exposure. This makes the records illegible and at risk of loss unless they are

timely transferred to a new booklet. Furthermore, there is a risk of the document being lost or forgotten when visiting immunization services. The absence of recorded information leads primarily to two problems: unnecessary revaccination, which increases service time, results in wasted vaccine doses, and necessitates a new booklet, and the risk of compromised vaccine coverage due to missed appointments, leaving the individual unprotected and undermining the goals of immunization policies¹.

Thus, to address these issues and integrate education and health, the decision was made to use mobile technology to promote care, given that technology is transforming many social activities, including those related to health, and directly impacting people's quality of life. Technological innovations are known to play a decisive role in societal development, contributing to economic growth and public well-being, as well as extending the duration of a high-quality human life; consequently, the healthcare industry cannot afford to lag in the face of the revolution in mobility and information and communication technologies^{7,8}. Just as the importance of preventing the loss or destruction of information derived from vaccination activities is emphasized, so too is the need for secure, computerized record-keeping that enables interoperability between public and private networks, given that patients and clients commonly utilize both healthcare service networks.

Given the above, this study aimed to reflect on the need for and potential of developing digital technologies, particularly mobile applications, for managing immunization care, considering the challenges associated with paper-based records and contemporary demands for secure, interoperable, and integrated record-keeping across public and private networks.

Methodology

This is a descriptive and critical reflective study, conducted in 2018, involving an analysis of published studies and official documents from the relevant institutions. To establish the theoretical framework, a bibliographic search was conducted across national and international databases, without restricting publication dates, to encompass the historical and conceptual evolution of the topic. Although the Latin American biomedical community primarily uses PubMed and SciELO, other fields of knowledge have employed alternative search sources, with Google Scholar (GS) being the main tool. Despite some researchers' reservations regarding the use of Google Scholar, a study⁹ demonstrated that this database is more efficient, both qualitatively and quantitatively, at retrieving scientific articles in the field of medical education, thereby justifying its adoption in the present study. After testing various combinations of descriptors, such as vaccines, apps, informatics, immunobiologicals, and technologies, among others, in different positions and using Boolean operators, it was determined that using the descriptors "technology AND immunization" in Google Scholar was the strategy best suited to the research objectives. The initial search yielded 13,001 publications. After the first exclusion, removing



factors, as well as by incidents during early campaigns^{19,20}. The successful eradication of smallpox boosted investment in immunization between 1973 and 1980, a period that saw the establishment of a technical and institutional foundation for controlling prevalent diseases. The 1970 reform created the National Department of Disease Prophylaxis and Control, consolidating vaccination activities that had previously been fragmented across vertical programs and state health departments. The National Poliomyelitis Control Plan (1971) enabled the accumulation of experience through state-level campaigns, albeit without a nationally structured system of epidemiological surveillance^{21,22}.

As the National Immunization Program (PNI) evolved, Reference Centers for Special Immunobiologicals (CRIEs) were established in 1993 to serve groups with specific immunization needs. The PNI aims to vaccinate 100% of children under one year of age, achieving minimum coverage rates of 95% for the tetravalent, polio, hepatitis B, and MMR vaccines, and 90% for the BCG vaccine; it also targets 100% coverage for the adult dual-antigen vaccine (diphtheria and tetanus) among women of childbearing age in at-risk municipalities^{3,11,23}. Although vaccination coverage has improved since the 1980s, regional inequalities and risk factors associated with non-vaccination persist, such as low income, low maternal education, transportation difficulties, and missed vaccination opportunities within health services^{4,6,24}.

The establishment of the Brazilian Society of Immunization (SBIIm) in 1998 brought together professionals from various specialties with the shared goal of scientific updating, the development of immunization schedules, engagement with public agencies, and the promotion of vaccines as a vital public health tool. Currently, three institutions issue vaccination schedules in Brazil: the Ministry of Health (PNI), the Brazilian Society of Pediatrics (SBP), and SBIIm, which publishes updated schedules annually for different age groups^{16,25}. While the PNI aims to immunize the population to prevent outbreaks and epidemics, scientific societies seek to maximize the immunization of each individual against vaccine-preventable diseases. Vaccination is one of the most cost-effective public health interventions; it is estimated to prevent the deaths of approximately 3 million children annually, contributing to increased longevity and improved quality of life²⁶.

The vaccination record and the management of vaccination data by government agencies and individuals

The vaccination record book, introduced by Oswaldo Cruz in 1904, remains, more than a century later, the primary means of recording vaccine doses and boosters for children, young people, adults, and the elderly; its correct completion and updating are essential for the full efficacy of the immunobiologicals¹¹. However, because it relies on paper as a physical medium, the vaccination card is susceptible to degradation caused by physical and chemical agents, constant handling, improper storage, humidity, the passage of time, and exposure to light. This can render records illegible or result in their loss, leading to two main problems: unnecessary revaccination, entailing wasted

publications that did not involve use in humans, 3,461 publications remained. A second exclusion, removing works not available in full text, left 2,271 publications. A third exclusion, performed after reading the abstracts, left 196 publications. Finally, a fourth exclusion, conducted after reading the full texts, resulted in the inclusion of 39 publications in the final stage of the analysis. Based on the reading, systematization, and analysis of the selected material, it was possible to identify three major thematic categories that guided the structure of the review: Historical Retrospective of the Implementation of Immunization Programs in Brazil and the New Approach of the Brazilian Society of Immunization; Vaccination Records and the Management of Vaccination Data by Government Agencies and Individuals; and Information Technologies as a Tool for Health Promotion.

Results and Discussion

Historical overview of the implementation of immunization programs in Brazil and the new approach of the Brazilian Society of Immunization

The National Immunization Program (PNI), coordinated by the Ministry of Health in partnership with state and municipal health departments, is recognized as one of the most significant public health interventions, with achievements such as the eradication of poliomyelitis, the elimination of indigenous rubella virus circulation, and a significant reduction in vaccine-preventable diseases, contributing to a decline in infant mortality and an increase in life expectancy^{3,10}. Established in 1973, the PNI consolidated actions that were previously fragmented into vertical programs targeting specific diseases—such as smallpox, tuberculosis, and polio—thereby defining the national vaccination schedule and allowing states to adopt complementary measures. Funded by public resources, the program is universal and equitable, coordinating technical standards as well as the procurement, storage, and distribution of immunobiologicals across the entire country^{6,11,12}.

The 1970s and 1980s marked the implementation of the PNI and the National Self-Sufficiency Program, consolidating public health planning, professional training, scientific and technological advancement, and the guarantee of citizenship. Brazil incorporated a large proportion of internationally available vaccines, many involving high technological complexity, produced by national public laboratories such as Bio-Manguinhos/Fiocruz and the Butantan Institute, enjoying a high level of trust among the public and scientific communities^{7,13,14}.

By inducing active immunity, vaccines are powerful tools for controlling and eliminating infectious diseases, although their efficacy and reactogenicity vary depending on their composition and production process^{15,16}. The incorporation of new vaccines into the PNI follows epidemiological, technological, immunological, socioeconomic, logistical, and cost-related criteria¹⁷. Safety is guaranteed by a rigorous assessment by Anvisa¹⁸. However, vaccination faced crises of acceptance influenced by demographic, socioeconomic, religious, and political



consultations, and care for chronic patients and high-risk pregnant women, thereby expanding the reach of primary care³⁰.

For mobile application development, it is necessary to review software engineering concepts, select an appropriate development model (sequential, iterative, or spiral), and adopt frameworks based on best practices to ensure quality and adherence to estimated timelines and costs³⁶. The success of the PNI depends on the continued sharing of responsibilities among all social actors¹². The Brazilian government and funding agencies need to define strategies to position the country competitively on the international stage, overcoming regulatory barriers and investing in innovation and technological development in immunobiologicals^{14,37}. Information technology facilitates decision-making and enhances the delivery of care, creating a growing need for technologies aimed at the systematization of nursing practice³⁸. The development of mobile applications linked to scientific health research is crucial, as their content is analyzed and tested by professionals who understand the users' actual needs. We are living in an era of personal and technical mobility where mobile devices are ubiquitous, offering the opportunity to design learning and care in innovative ways, connecting people in real time and creating learning communities^{34,39}.

Conclusion

The development of applications for the management of human care, whether through direct intervention actions, management, or health education, appears to be a need to be addressed by health professionals, who have the mission of becoming technology producers rather than mere consumers. In the field of vaccines, many individuals remain exposed to the risks of non-vaccination or the administration of unnecessary extra doses, since the paper vaccination card, a technology in use since the 1970s, is no longer sufficiently efficient in meeting the demands of contemporary society. Coupled with the needs imposed by globalization and the (re)positioning of all social actors, including in remote areas that already make use of mobile technology and applications, the need for mobile applications to manage the production, storage, distribution, and control of vaccines and immunobiologicals becomes undeniable. It is expected that the results of this research will awaken in health professionals and care managers an interest in the production of new technological knowledge, which will not only meet an already expressive population demand but also benefit the professionals themselves, since such technologies are expected to reduce costs related to the production and storage of paper cards and, above all, reduce risks for all those involved in the immunization process.

Finally, we call upon researchers in the vaccine field to develop technologies aligned with the needs of the population in the new era, as well as to ensure that theories of virtual care and the understanding of public behavior regarding the use of electronic devices and health applications are better studied and disseminated among their peers.

doses and increased service time, and the risk of compromised vaccination coverage due to missed appointments, leaving the individual unprotected and undermining the goals of immunization policies¹.

Studies reveal challenges faced by healthcare professionals in managing the health record booklet, such as failure to record data, high patient volume, bureaucracy, communication gaps, and a lack of appreciation by families, indicating a need to reorganize services and implement educational activities²⁷. Systematizing this information in a digital format, with data available via a network, emerges as a viable alternative to avoid such problems. The PNI began computerization efforts in 1994, albeit in their early stages. It is evident that the booklets lack space for recording adverse events and fail to provide users with clear information on how to report them, which limits their utility²⁵. At the same time, anti-vaccination movements, amplified by social media and celebrities, spread distrust and put vaccination coverage at risk²⁸.

Technological advances have enabled the development of vaccines against diseases that previously lacked preventive measures, such as dengue and schistosomiasis, using recombinant DNA technology, thereby broadening the spectrum of protection²⁹. Reflecting on the health work process is essential for improving the quality of care, and the virtualization of the health record book has been identified as a resource to make life easier for professionals, managers, and patients¹². The miniaturization of processors and electronic components has transformed mobile phones into high-performance smartphones, making mobile technology widely accessible. The information age has moved beyond standard administrative functions and now plays a fundamental role in patient care, prescribing, prevention systems, and vaccine utilization^{1,30}.

Information technologies as a tool for health promotion

Information and Communication Technologies (ICTs) have been transforming social relations and the interaction between government and citizens, with the increasing availability of information and services through applications and social networks¹. According to IBGE³¹, 54.4% of Brazilians access the internet daily, with mobile phones being the preferred device for browsing, a trend that has fostered digital inclusion. The universal adoption of ICTs directly influences societal habits and impacts the healthcare sector and comprehensive care³². Technological evolution, from the Von Neumann architecture to modern smartphones, combined with the development of the Internet and social media, has created an ecosystem favorable to the provision of digital health services^{1,33}.

In the government sector, ICT-based systems are widely used for accessing test results, automating medical records, and managing population data, aiming for greater efficiency in service delivery¹. The adoption of mobile devices by healthcare professionals is high, and there is evidence that professionals with access to reference tools and continuing education provide better care, with a positive impact on vaccination coverage^{34,35}. Telemedicine enables remote medical interventions, such as second opinions,



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