

REVIEW

Advances and Challenges in the Use of Biomechanics-Inspired Digital Technologies for Managing Pediatric Chronic Diseases: A Systematic Review

Avances y Desafíos en el Uso de Tecnologías Digitales Inspiradas en la Biomecánica para el Manejo de Enfermedades Crónicas Pediátricas: Una Revisión Sistemática

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ABSTRACT

This study aims to systematically review biomechanics-inspired digital technologies applied in the management of pediatric chronic diseases, focusing on their effectiveness, limitations, and implementation challenges. Following PRISMA 2020 guidelines, a comprehensive search was conducted in Web of Science, Scopus, and Google Scholar. Studies were included if they addressed pediatric patients (0-18 years) and involved digital health interventions integrating biomechanical data or telemedicine solutions. A total of 20 peer-reviewed studies were selected after screening 368 records. Data extraction included study design, technologies, health outcomes, and implementation barriers. mHealth platforms demonstrated treatment adherence rates up to 80 % in cystic fibrosis, while therapeutic video games improved quality of life and psychological well-being in pediatric cancer patients. Telemedicine significantly reduced hospitalization and improved follow-up attendance, particularly in diabetes and asthma cases. Advanced technologies, such as wearable motion sensors, robotic exoskeletons, and continuous glucose monitoring, enhanced rehabilitation outcomes and personalized treatment. Despite these benefits, barriers included high development costs, limited digital literacy, infrastructure gaps, and ethical concerns related to data privacy. Biomechanics-inspired digital technologies significantly enhance adherence, rehabilitation, and quality of life for children with chronic illnesses. However, widespread implementation requires addressing structural barriers, ensuring equitable access, and integrating culturally sensitive solutions. Future research should focus on adaptive tools, long-term evaluations, and strategies to bridge technological and socioeconomic gaps in pediatric healthcare.

Keywords: Digital Health Technologies; Pediatric Chronic Diseases; Biomechanics; Telemedicine; mHealth Platforms; Therapeutic Video Games.

RESUMEN

Este estudio tiene como objetivo revisar de forma sistemática las tecnologías digitales inspiradas en la biomecánica aplicadas en el manejo de enfermedades crónicas pediátricas, centrándose en su efectividad, limitaciones y desafíos de implementación. Siguiendo las directrices PRISMA 2020, se realizó una búsqueda exhaustiva en Web of Science, Scopus y Google Scholar. Se incluyeron estudios que abordaran pacientes

pediátricos (0-18 años) y que involucraran intervenciones de salud digital que integraran datos biomecánicos o soluciones de telemedicina. Un total de 20 estudios revisados por pares fueron seleccionados tras el cribado de 368 registros. La extracción de datos incluyó diseño del estudio, tecnologías utilizadas, resultados en salud y barreras de implementación. Las plataformas mHealth demostraron tasas de adherencia al tratamiento de hasta el 80 % en fibrosis quística, mientras que los videojuegos terapéuticos mejoraron la calidad de vida y el bienestar psicológico en pacientes pediátricos con cáncer. La telemedicina redujo significativamente las hospitalizaciones y mejoró la asistencia a seguimientos, especialmente en casos de diabetes y asma. Tecnologías avanzadas, como sensores de movimiento portátiles, exoesqueletos robóticos y monitoreo continuo de glucosa, mejoraron los resultados de rehabilitación y la personalización del tratamiento. A pesar de estos beneficios, persistieron barreras relacionadas con los altos costos de desarrollo, la baja alfabetización digital, las limitaciones de infraestructura y las preocupaciones éticas sobre la privacidad de los datos. Las tecnologías digitales inspiradas en la biomecánica mejoran significativamente la adherencia, la rehabilitación y la calidad de vida de los niños con enfermedades crónicas. Sin embargo, su implementación generalizada requiere superar barreras estructurales, garantizar el acceso equitativo e integrar soluciones culturalmente sensibles. La investigación futura debe centrarse en herramientas adaptativas, evaluaciones a largo plazo y estrategias para reducir las brechas tecnológicas y socioeconómicas en la atención pediátrica.

Palabras clave: Tecnologías de Salud Digital; Enfermedades Crónicas Pediátricas; Biomecánica; Telemedicina; Plataformas mHealth; Videojuegos Terapéuticos.

INTRODUCTION

Approximately 40 % of children and adolescents suffer from at least one chronic disease, with obesity/overweight, eczema, and asthma being the most common conditions in childhood in the United States.⁽¹⁾ Other conditions include type 1 diabetes, cystic fibrosis, and various forms of pediatric cancer. Chronic diseases in children not only pose immediate health challenges but also have enduring consequences, affecting their physical development, emotional well-being, and social interactions. Data indicate that chronic illnesses in children affect millions worldwide and have a profound impact on quality of life, family relationships, and household finances.⁽²⁾

Technology stands out as a remedy for these obstacles. Recently, the adoption of digital health solutions has increased, presenting novel methods for handling chronic illnesses. As noted by Opipari-Arrigan et al.⁽³⁾ and Kaplan et al.⁽⁴⁾, digital platforms significantly boosted adherence to treatment plans. These platforms frequently include features such as medication reminders, educational content, and interactive elements that actively involve children in their health care. These technological advancements not only improve the physical and emotional well-being of children but also enhance the efficiency of the healthcare system by minimizing unnecessary hospital stay and emergency room visits.⁽⁵⁾ By facilitating seamless communication between patients and health care providers, technology enables timely interventions that can avert complications and enhance overall health outcomes.

For example, mobile health solutions such as the Orchestra platform have achieved up to 80 % adherence rates in cystic fibrosis patients, while the Genia app in Sweden improved real-time monitoring and communication between patients and providers.⁽⁶⁾ and Liu et al.⁽⁸⁾, these technologies have “enabled children to receive high-quality care regardless of their location.” This advancement is particularly advantageous for families in remote regions, where healthcare options are scarce. These innovations have been groundbreaking for those with children suffering from chronic illnesses who live far from hospitals. Telemedicine not only grants access to medical expertise, but also provides reassurance to families who might otherwise feel alone in handling complex health issues.

Therapeutic video games have brought a playful aspect to treatment by engaging children in an enjoyable and interactive way that makes managing their conditions less intimidating. As noted by Bruggers et al.⁽⁹⁾, these games empower patients by providing them with a sense of control and influence over their condition. Furthermore, the e-Powered Parents Program, highlighted by Geense et al.⁽¹⁰⁾, has been found to alleviate parental stress and enhance children’s quality of life. This initiative provides parents with the necessary knowledge and tools to effectively support their children, promoting a collaborative healthcare approach that benefits the entire family.

Two studies, Nkoy et al.⁽¹¹⁾ and Yeung et al.⁽¹²⁾ emphasized ongoing issues related to economic accessibility, the availability of technological infrastructure, and sufficient user training. Many families struggle to afford the devices or Internet services necessary to fully engage with these technologies. Furthermore, disparities in technological infrastructure can create obstacles for certain groups, thereby worsening the existing health disparities. Despite these advantages, it is crucial to tackle the technical and social challenges of

implementing these technologies, such as development costs, cultural acceptance, and thorough evaluation of their effectiveness in diverse pediatric populations.⁽¹³⁾ This requires collaborative effort from policymakers, healthcare providers, and technology developers to ensure that digital health solutions are accessible, effective, and culturally suitable for all families.

Biomechanics play a crucial role in the development of digital technologies aimed at managing chronic illnesses in children. For instance, mHealth platforms equipped with motion sensors analyze the walking patterns of children with cerebral palsy by utilizing biomechanical models to detect abnormalities and adjust rehabilitation therapies accordingly. Similarly, robotic exoskeletons employ kinematic and dynamic principles to provide personalized support and modify assistance based on the residual mobility and force distribution of the user. Moreover, therapeutic video games with biomechanical feedback systems measure real-time metrics such as movement speed, joint motion range, and applied force. These technologies enable automated adjustments to therapy, ensuring a personalized rehabilitation experience tailored to each patient's biomechanical data.

Although digital health solutions are becoming increasingly common in pediatric care, there is a lack of systematic research on how biomechanics-inspired technologies affect the management of chronic illnesses in children. The literature reveals a gap concerning the comparative effectiveness of these tools, their integration into clinical practice, and their long-term sustainability across diverse populations. To address this gap, the present study is guided by the following research questions:

- What biomechanics-based digital technologies are currently employed in the management of chronic pediatric diseases?
- What benefits and limitations are identified in the existing literature concerning these technologies?
- What are the primary obstacles to their implementation, and what future research directions should be pursued to enhance their effectiveness and accessibility?

This paper is organized as follows: Section 2 delineates the methodology and inclusion criteria, adhering to PRISMA guidelines. Section 4 presents the principal findings, categorized by type of technology. Section 5 discusses the implications of these results, identifies barriers and ethical concerns. Section 6 offers concluding remarks and summarizes the study's contributions.

METHOD

This study undertook a systematic literature review (SLR) following the PRISMA 2020 guidelines,⁽¹⁴⁾ which provides a structured approach to identify, select, and critically assess relevant studies. Unlike earlier reviews that generally covered digital health or specific medical conditions, this review concentrates on biomechanics-inspired digital technologies used to manage chronic diseases in children. It compiles evidence from three main databases, Web of Science, Scopus, and Google Scholar, to ensure thorough coverage, including both peer-reviewed articles and open-access literature often overlooked in past analyses. Furthermore, it organizes findings by technology type (e.g., mHealth platforms, telemedicine, and therapeutic games) and assesses their effectiveness using comparative metrics. This method offers a wider and more detailed understanding of the field, especially concerning the use of biomechanical principles to improve personalized treatment and rehabilitation in children.

Information Sources

The literature search utilized several databases, including Web of Science (WoS), known for its extensive coverage in health and social sciences;⁽¹⁵⁾ Scopus, recognized for its broad interdisciplinary reach and comprehensive indexing of relevant articles across various fields;⁽¹⁶⁾ and Google Scholar, which provides access to recent and region-specific research, aiding in the discovery of open-access versions of documents that might be restricted on other platforms.⁽¹⁷⁾

Search Strategy

A thorough search strategy was employed, utilizing keywords pertinent to digital technologies, chronic conditions, and the pediatric demographic. The search terms used were TS=(“pediatric chronic diseases” OR “pediatric chronic illnesses” AND “technology”) for the Web of Science (WoS) database and TITLE-ABS-KEY(“pediatric chronic diseases” OR “pediatric chronic illnesses” AND “technology”) for Scopus. In Google Scholar, open keyword searches such as “pediatric chronic diseases,” “pediatric chronic illnesses,” and “technology” were conducted.

Inclusion and Exclusion Criteria

The search approach utilized specific filters to narrow down the results, ensuring that only studies that met the established criteria were included. The applied filters included:

- Language: English and Spanish

- Study Type: Original research articles (excluding editorials, commentaries, and conference abstracts)
- Population: Studies focusing on pediatric patients (ages 0-18)
- Technology Scope: Digital health interventions utilizing biomechanical data or telemedicine solutions
- Publication Status: Peer-reviewed journal articles

To ensure comprehensive coverage, reference lists of relevant articles were also manually screened for additional studies that met the inclusion criteria.

The heterogeneity of the included studies stems from multiple sources, including variability in inclusion criteria, different measurement methods, and the diverse range of technologies analyzed. Some studies focused on motion-sensing devices to assess patient biomechanics, whereas others examined telemedicine solutions without direct biomechanical evaluation. Additionally, the studies covered a wide range of pediatric conditions, age groups, and intervention levels.

Given this degree of heterogeneity, conducting a meta-analysis is not feasible, as the included studies exhibit substantial methodological differences in measured parameters and evaluated outcomes. However, categorizing findings based on technology type and clinical application enhances result comparability.

Selection Process

Our research yielded a total of 368 documents: 10 from Scopus, 38 from WoS, and 320 from Google Scholar. After removing duplicates (n=35), 333 titles and abstracts were assessed for relevance, including 124 full-text articles. We identified 20 studies related to the assistance or guidance of children and adolescents with chronic diseases (see figure 1).

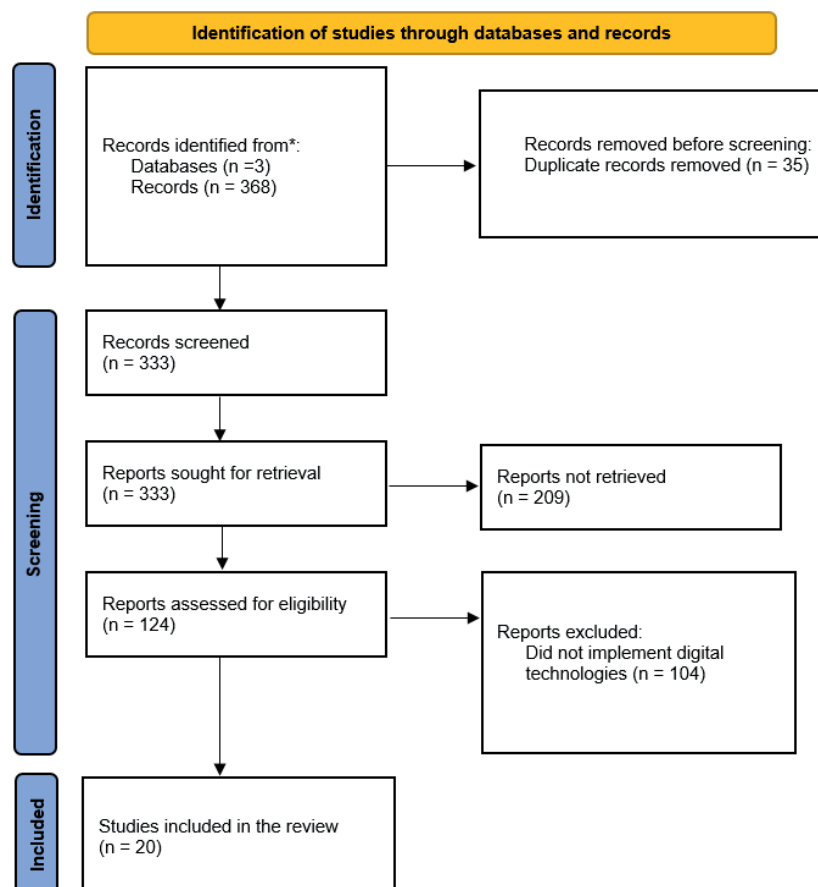


Figure 1. PRISMA Flow Diagram for Study Selection

The key findings from the reviewed studies are summarized below:

Benefits of digital health technologies in pediatric chronic disease management:

- Improved treatment adherence, particularly with mHealth platforms and mobile observed therapy (MDOT) (e.g., 80 % adherence in cystic fibrosis patients).

- Enhanced quality of life, especially through therapeutic video games and telemedicine (e.g., improved psychological well-being in pediatric cancer patients).
- Reduction in hospitalization rates, notably in conditions such as type 1 diabetes and asthma.
- Increased patient and family engagement in disease management, with digital interventions supporting parental involvement and stress reduction.

A pilot experiment involving 20 records was conducted by three researchers to clarify and refine the inclusion and exclusion criteria. After removing duplicates, the titles and abstracts of the records were independently reviewed by the three researchers. When the information obtained was insufficient or consensus was not reached, a full-text assessment was required. Full texts were evaluated for eligibility, and discrepancies among researchers were resolved through discussion with a fourth investigator.

Data Extraction

Data were extracted on publication year, country of study, technology used, type of disease addressed, and key findings. A pilot test, including five full-text articles, helped refine the categories and documentation requirements. Data extraction was conducted independently by two researchers.

Risk of Bias Assessment

The risk of bias assessment was conducted using the Joanna Briggs Institute's critical appraisal checklists.⁽¹⁸⁾ Bias was assessed individually, and discrepancies were resolved through discussion, without the need to involve a third researcher. This assessment did not lead to additional inclusion or exclusion decisions.

RESULTS

Technology	Key Metric	Observe Results	References
Plataforma mHealth	Treatment adherence	80 % weekly adherence (cystic fibrosis)	(3)
Telemedicine	Hospitalization reduction	Significant reduction in children with diabetes	(19)
Therapeutic video games	Quality of life	Physical and psychological improvement in cancer patients	(9)
Continuous glucose monitoring	Glycemic control	Significant improvement in type 1 diabetes patients	(20)
MDOT	Treatment adherence	Over 90 % adherence in children with acute lymphoblastic leukemia	(22)
ETIOBE Platform	Health habit changes	Promotion of healthy habits and reduction of relapses in childhood obesity	(21)
Virtual telepharmacy	Error reduction	Increased medication education and adherence	(7)
Advanced electronic tracker	Symptom control	Reduced hospitalizations and school absences in pediatric asthma	(11)

Table 1 presents a summary of these technologies, the key metrics evaluated, and the observed results, allowing for a clearer visualization of their effectiveness in the reviewed studies. The characteristics of the included studies are shown in figure 2.

mHealth Platforms and Mobile Applications

The digital revolution in the treatment of pediatric chronic diseases has been widely documented, and our review confirms its transformative impact on pediatric healthcare. Among the 20 studies analyzed in this systematic review, five focused specifically on mHealth platforms, demonstrating their role in improving treatment adherence, patient engagement, and communication between families and healthcare providers.

For example, Opipari-Arrigan *et al.*⁽³⁾ and Kaplan *et al.*⁽⁴⁾ evaluated the Orchestra platform, an innovative solution designed for young individuals living with cystic fibrosis and inflammatory bowel disorders. Their findings reported that 80 % of patients maintained consistent weekly interaction with the platform, which enhanced real-time monitoring, improved disease self-management, and facilitated communication with healthcare teams.

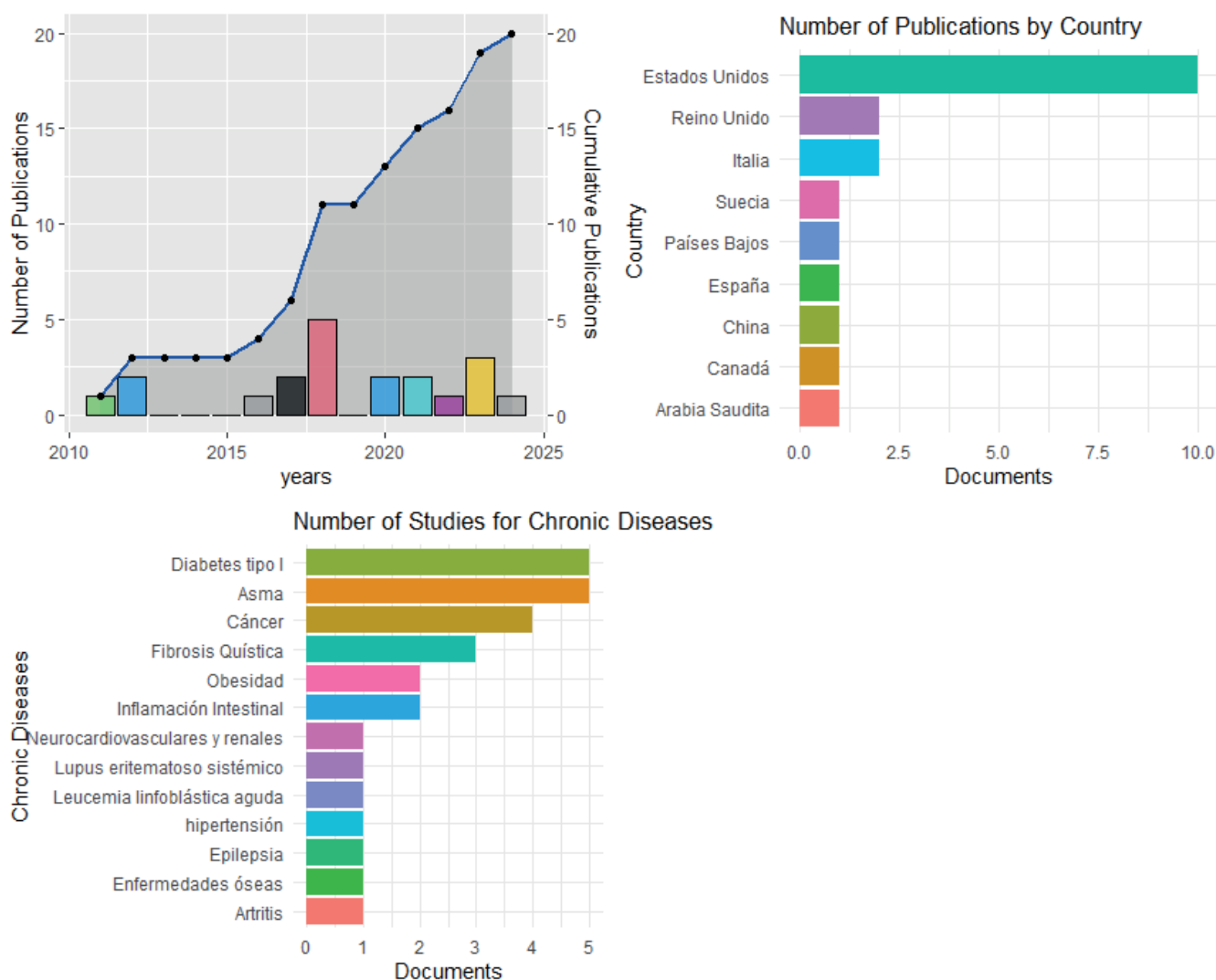


Figure 2. Characteristics of the selected studies

Similarly, Longacre et al.⁽⁶⁾ examined the Genia app in Sweden, which integrates continuous monitoring and collaborative decision-making with patients and families. Their results attributed the app's success to its participatory design process, involving both children and caregivers in development, which increased engagement and adherence.

In Spain, Baños et al.⁽²¹⁾ studied the ETIOBE platform for childhood obesity management. The intervention combined continuous health tracking and educational gaming components, resulting in significant improvements in children's healthy habits and treatment compliance.

Furthermore, Geense et al.⁽¹⁰⁾ analyzed the HealthCHAT program in the United Kingdom, designed to support parents of children with chronic illnesses. Their findings revealed that parents experienced reduced emotional stress, greater confidence in managing their child's condition, and better communication with healthcare professionals. However, they also reported technical challenges that limited the user experience and required further refinement.

Telemedicine and Remote Monitoring

Recent progress in telemedicine has led to notable improvements in managing chronic diseases in children, as evidenced by recent research. Studies by ⁽⁵⁾ and ⁽¹⁹⁾ highlighted significant results, particularly in the treatment of type 1 diabetes and other pediatric conditions. One major discovery from these studies was that patients with access to telemedicine services were 3.55 times more likely to attend quarterly clinical appointments in Oregon, highlighting the direct influence of this technology on maintaining consistent treatment.

The implementation of virtual telepharmacy clinics has yielded promising results. In Saudi Arabia, Alassadi et al.⁽⁷⁾ documented the benefits of this system in a study involving 1 955 pediatric patients over a 20-month period. The findings indicated significant improvements in medication education, reduction in administration errors, and notable increase in patient and family satisfaction.

In the field of managing pediatric asthma, a study by Nkoy et al.⁽¹¹⁾ in the United States assessed the effectiveness of different electronic monitoring devices. The results showed that both basic and sophisticated trackers considerably improved patients' quality of life and asthma management, leading to fewer visits to the emergency department. Importantly, advanced trackers that incorporate reward-based systems provide an extra advantage by promoting greater adherence to treatment plans.

This research offers strong evidence of the transformative effects of telemedicine and virtual clinics in managing chronic pediatric care. The results demonstrate notable improvements in the quality and accessibility of healthcare, effectively overcoming geographical barriers and allowing for continuous patient monitoring. These technological innovations not only enhance the delivery of healthcare but also fundamentally change how chronic pediatric patients receive their care.

Comprehensive Management Models

Comprehensive management frameworks have proven effective in tackling pediatric chronic illnesses by merging digital innovations with holistic care approaches.

The "Internet Plus" model in China, as analyzed by Liu et al.⁽⁸⁾, stands out for significantly boosting patient and caregiver satisfaction, decreasing hospital admissions, and quadrupling follow-up visits. This method has shown itself to be a thorough and successful strategy for handling various pediatric chronic conditions, thereby enhancing both clinical results and patient experiences.

In contrast, the Netherlands' digital initiative "e-Powered Parents," assessed by Geense et al.⁽¹⁰⁾ potentially leading to negative effects on their child's health outcomes. Although the experienced problems are well known, adequate (online, focused on empowering families through adaptable interventions. This program not only reduced parental stress but also improved the well-being of children with chronic kidney diseases, highlighting the importance of actively involving families in the care process.

In summary, these models highlight the potential of integrated technologies to transform the management of pediatric chronic diseases, fostering care that is more personalized, participatory, and patient-centered.

Video Games and Digital Therapies

Digital therapies, including video games tailored for young patients, have proven effective in enhancing both the quality of life and compliance with treatment plans.

The video game Empower Stars!, created by Bruggers et al.⁽⁹⁾ has been found to positively impact the physical and mental health of children with pediatric cancer. Participants particularly valued the rewards and interactive elements, which empowered them in managing their condition. Additionally, mobile observed therapy (MDOT), as studied by Faber⁽²²⁾, improved treatment adherence in children with acute lymphoblastic leukemia, achieving adherence rates above 90 % over a three-month period through personalized reminders and educational videos.

Internet-Based Programs

Digital self-management programs have improved both the accessibility and compliance with chronic disease management strategies for pediatric patients.

According to Stinson & Gill,⁽²⁾ these platforms have proven effective in handling conditions like arthritis, asthma, and diabetes, highlighting their capacity to provide a collaborative and easily accessible experience. Additionally, text message reminders, studied by Yeung et al.⁽¹²⁾ improved clinical appointment attendance in adolescents with systemic lupus erythematosus, though their impact on medication adherence was limited.

Advanced Technologies

Various advanced technologies have introduced innovative solutions for monitoring and managing pediatric chronic diseases.

According to Nieto González et al.⁽¹³⁾ polymeric and lipid nanoparticles are emerging as innovative solutions for the treatment of pediatric cancer, hypertension, asthma, and chronic parasitic diseases. These technologies have improved the effectiveness and safety of treatments by ensuring the stable and accurate delivery of hydrophobic drugs.

The use of biomechanical models has significantly increased the success of digital interventions. Wearable motion sensors are used to measure gait abnormalities and provide clinicians with objective data on motor impairments. Studies on force feedback rehabilitation exoskeletons have shown better mobility outcomes than traditional therapies alone. Moreover, real-time biomechanical tracking in therapeutic gaming increases patient engagement, thus enhancing adherence to rehabilitation programs. Additionally, continuous glucose monitoring and artificial pancreas systems, as explored by Liberman & Buckingham,⁽²⁰⁾ have greatly advanced glucose control and quality of life in individuals with type 1 diabetes. Nonetheless, the intrusive alarms and emotional strain linked to these systems have hindered their widespread acceptance.

Technology-Based Family Interventions

Technological strategies aimed at improving family interactions have proven effective in managing chronic diseases among children. As noted by Canter et al.⁽²³⁾ these strategies have been found to improve family communication and reduce conflict-related issues in handling pediatric conditions like asthma, cancer, obesity, and type 1 diabetes.

Common Findings

The analyzed studies underscore several significant advantages of digital technologies in the management of pediatric chronic diseases:

Adherence to Treatment: The use of digital tools has been demonstrated to boost adherence to medication regimens and compliance with scheduled clinical visits, which, in turn, leads to better therapeutic results.

- **Enhancement of Quality of Life:** Innovations like video games, mobile health (mHealth) applications, and telemedicine have given both patients and their families more control, enhancing their physical and emotional health.
- **Mitigation of Access Barriers:** Telemedicine services and online platforms have successfully overcome geographical challenges, offering significant advantages to people living in rural or isolated regions.
- **Family Participation:** Personalized programs that actively involved caregivers and families demonstrated greater effectiveness in managing chronic conditions.

DISCUSSION

This systematic review confirmed that digital technologies play a crucial role in revolutionizing the management of chronic diseases in children. They do so by boosting self-management, enhancing adherence to treatment, and improving communication between patients, caregivers, and healthcare providers. The key tools in this transformation include mHealth platforms, telemedicine, therapeutic video games, and advanced technologies, although their adoption faces technical, economic, and cultural hurdles.

mHealth platforms and mobile apps have been shown to have a significant influence on improving self-management in children with chronic illnesses. These digital solutions enable children and their families to play an active role in managing health conditions and promoting a sense of independence and accountability. For instance, the Orchestra platform, used by patients with cystic fibrosis, resulted in an 80 % increase in weekly treatment adherence, thereby enhancing collaboration between patients and physicians.^(3,4) In Europe, the Genia app, created through a participatory process, effectively boosted treatment adherence among children with cystic fibrosis, highlighting the importance of involving patients and their families in the development of these technologies.⁽⁶⁾ By integrating user feedback, developers can design more relevant and engaging applications that connect with their intended audience. These results align with earlier research that emphasizes the significance of user-centered technologies in enhancing health outcomes.⁽²⁾ This user-focused strategy not only improves the effectiveness of these platforms but also fosters trust and encourages ongoing user engagement.

Telemedicine has become a crucial strategy for overcoming the obstacles to healthcare access. This cutting-edge method allows healthcare professionals to connect with patients who may face significant challenges in receiving care. In the United States, the use of telemedicine services has increased the likelihood of pediatric patients with type 1 diabetes attending their regular clinical appointments by 3,55 times.⁽⁵⁾ Virtual telepharmacy clinics in Saudi Arabia have educated over 1 900 patients about their medications, leading to fewer errors and greater family satisfaction.⁽⁷⁾ These clinics are essential resources that help families to understand their medication plans and manage their children's health conditions more effectively. These findings highlight the effectiveness of telemedicine in maintaining continuous care, especially in rural or remote locations, although technical issues, such as the need for strong connectivity and accessible devices, remain.^(8,11) Overcoming these challenges is vital to fully realize the advantages of telemedicine, ensuring that all families can access high-quality healthcare regardless of where they live.

Combining digital health technologies with conventional medical treatments and behavioral therapies is essential for improving the management of chronic illnesses in children. For example, mobile health (mHealth) platforms can complement traditional physical therapy by providing real-time tracking of motor skills and compliance with prescribed rehabilitation activities. Healthcare professionals can use data from wearable motion sensors to dynamically adapt therapy plans, ensuring that treatment is tailored to individual needs.

Telemedicine platforms that integrate biomechanical evaluations can improve remote patient assessments, thereby minimizing the need for frequent in-person appointments, while maintaining high standards of care. In the field of behavioral therapy, digital solutions such as gamified cognitive-behavioral therapy (CBT) apps have shown potential in engaging children with chronic illnesses, thus enhancing compliance with psychological treatment. By incorporating these technologies into multidisciplinary healthcare frameworks, clinicians can offer more comprehensive and accessible treatment options to pediatric patients.

Video games and digital therapies represent a rapidly growing area of research with significant potential. In pediatric oncology, Empower Star! Video games have been demonstrated to improve both physical and mental quality of life, while also enhancing patient empowerment.⁽⁹⁾ Likewise, mobile observed therapy (MDOT) has boosted treatment adherence to 90 % in children with acute lymphoblastic leukemia, showing the effectiveness of personalized reminders and digital incentives.⁽²²⁾ These results align with research highlighting the positive impact of therapeutic video games in managing the emotional aspects of chronic illnesses.⁽²³⁾

However, even with these advancements, significant obstacles persist. Innovative technologies such as lipid and polymeric nanoparticles have the potential to revolutionize the management of pediatric diseases by enhancing the effectiveness and safety of treatment.⁽¹³⁾

The incorporation of biomechanical principles into digital health technologies has significantly improved rehabilitation outcomes in children. For instance, motion-sensing wearables gather and assess spatiotemporal gait data, offering clinicians accurate insight into motor function impairments. Robotic-assisted rehabilitation devices utilize force-feedback systems to adjust to the biomechanics of the user, enhancing the effectiveness of therapy. In therapeutic gaming, real-time biomechanical monitoring allows personalized difficulty adjustments, promotes adherence, and maximizes therapeutic gains. By integrating these biomechanical models, digital health solutions can better match patients' movement abilities and foster effective and personalized interventions.

Biomechanical principles play crucial roles in the development of digital rehabilitation tools. In designing therapeutic video games, kinematic models are used to evaluate limb movements and adjust game difficulty based on the patient's joint range of motion. Similarly, telemedicine platforms with gait analysis employ advanced algorithms to identify issues with postural stability and force distribution, aiding the early detection of neuromotor disorders in children. However, the implementation of these systems encounters obstacles related to development costs and necessitates further studies on clinical effectiveness. For instance, while the utilization of artificial pancreas systems in patients with type 1 diabetes has markedly enhanced glycemic control, it presents challenges, such as intrusive alarms and an increased emotional burden for families.⁽²⁰⁾

A major issue is unequal access to these technologies. While telemedicine and online platforms have the capability to overcome geographical limitations, their deployment is still limited in underprivileged areas owing to a lack of technological infrastructure and financial means.^(2,12) Additionally, the effectiveness of these interventions largely depends on the active participation of families, as demonstrated by the e-Powered Parents Program, which has been proven to alleviate parental stress and improve children's quality of life.⁽¹⁰⁾ However, it is crucial that these programs be adapted to fit the cultural and socioeconomic backgrounds of the intended populations to maximize their impact.

In summary, digital technologies represent a significant leap forward in managing pediatric chronic illnesses by providing innovative solutions that improve both quality of life and clinical outcomes. Nonetheless, to ensure their efficacy and fairness, it is essential to tackle technical, economic, and cultural obstacles as well as evaluate their sustainability and scalability in various settings. Future research should focus on customizing these tools and devising strategies to promote their adoption by vulnerable communities.

Comparison of Digital Technologies: Identifying the Most Effective Tools

This review underscores the notable effectiveness of mHealth platforms and therapeutic video games in improving adherence and quality of life (table 1). Key factors driving their success include user-focused design and innovative elements such as personalization and digital rewards. These technologies not only support patient self-management, but also encourage greater family participation.

Benefits and Limitations of Digital Technologies in Pediatrics

Digital technologies have profoundly reshaped the management of chronic diseases in children, bringing numerous advantages, such as better treatment adherence, enhanced quality of life, and greater access to healthcare services. These technological innovations allow health care providers to offer personalized care by customizing interventions to meet each child's unique needs. For example, mHealth platforms such as Orchestra have achieved an 80 % treatment adherence rate in cystic fibrosis patients,⁽³⁾ whereas therapeutic video games such as Empower Stars! have improved both the physical and psychological well-being of children with cancer.⁽⁹⁾ Additionally, advanced tools, such as lipid nanoparticles, have increased the effectiveness and safety of pediatric oncology treatments, enabling more stable delivery of hydrophobic drugs.⁽⁸⁾ This progress not only enhances treatment outcomes, but also minimizes side effects, making therapies more tolerable for young patients. However, these technologies present several significant challenges.

Despite their potential, the successful deployment of these tools often has hurdles that hinder their effectiveness. Although telemedicine can overcome geographical barriers, it relies on strong connectivity, which limits its use in rural areas.⁽⁸⁾ Similarly, mHealth platforms encounter cultural and technical resistance, particularly in vulnerable populations.⁽¹²⁾ This resistance may stem from unfamiliarity with the technology or distrust in digital health solutions. Finally, despite their effectiveness, therapeutic video games are limited

by high development costs and a lack of long-term studies evaluating their sustainability.⁽⁹⁾ Addressing these challenges is essential for maximizing the impact of digital technologies in pediatric healthcare. The effectiveness of digital health interventions in managing pediatric chronic diseases is heavily influenced by the digital literacy of both the patients and healthcare providers. A limited understanding of digital tools can hinder the adoption of technologies, such as mobile health (mHealth) platforms, therapeutic video games, and telemedicine solutions. The main challenge is ensuring that caregivers and pediatric patients can effectively navigate digital health platforms. Research has indicated that insufficient digital literacy can lead to reduced engagement and suboptimal adherence to treatment plans. To address this issue, health care providers should implement targeted educational programs to train patients and caregivers on the effective use of digital health solutions.

Furthermore, it is crucial for healthcare professionals to receive comprehensive training to accurately interpret biomechanical data obtained from digital tools. Incorporating digital health curricula into medical education and professional development programs can significantly enhance clinicians' abilities to use these technologies for personalized patient care. Additionally, ensuring that technology design is accessible and user friendly is vital for bridging the gap among populations with lower levels of digital literacy.

Ethical Consideration

The incorporation of digital technologies into the management of chronic pediatric illnesses raises significant ethical concerns, particularly regarding data privacy, security, and consent. Digital health platforms must comply with strict data protection laws, such as the Health Insurance Portability and Accountability Act (HIPAA) in the U.S. and the General Data Protection Regulation (GDPR) in Europe. Ensuring secure collection, storage, and transmission of sensitive biometric and medical information is crucial to prevent unauthorized access and data breaches.

Moreover, informed consent processes must be adapted for pediatric patients, where legal guardians make healthcare decisions for minors. It is vital to clearly communicate data collection practices and patient rights in order to foster transparency and trust. Additionally, addressing digital equity is necessary to prevent technological advancements from worsening the existing healthcare disparities. Initiatives such as subsidized access programs and tailored digital literacy efforts can help bridge this gap in underserved communities.

CONCLUSIONS

This systematic review demonstrates that biomechanics-inspired digital technologies represent a transformative advancement in the management of pediatric chronic diseases. By integrating motion-based data, real-time feedback, and digital health strategies, these innovations enable more personalized care, enhance patient empowerment, and provide new possibilities for accessible pediatric healthcare.

The findings reveal that these technologies are not simply tools for improving treatment adherence but are driving a paradigm shift toward patient-centered, data-driven, and technology-enabled pediatric care. They offer potential to reduce inequalities, optimize rehabilitation, and strengthen collaboration among patients, families, and healthcare providers.

Future research should focus on developing adaptive and inclusive solutions that ensure scalability, ethical integrity, and equitable access, particularly in low-resource settings. Integrating biomechanics-inspired technologies into pediatric healthcare requires strategic frameworks that align innovation, policy, and patient needs, setting the foundation for more sustainable and effective models of care.

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