SPECIAL ARTICLE

Advances in Pediatrics in the 21st Century: Pathways, Challenges and Perspectives

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Abstract

A Pediatrics in the 21st century is traversing a period of profound transformation, driven by scientific breakthroughs, technological innovation, and shifting social dynamic. The significant reduction in infant mortality – driven primarily by progress in neonatology, immunization, and humanized care – has fundamentally altered the epidemiological profile of childhood. Concurrently, there is a rising prevalence of chronic diseases, neurodevelopmental disorders, and mental health conditions, reinforcing the importance of comprehensive and early childhood care, aligned with the principles of the Developmental Origins of Health and Disease (DOHaD).

The integration of genetics and precision medicine has enhanced diagnostic accuracy, particularly for rare diseases, while gene and molecular-targeted therapies have opened new therapeutic horizons. Digital technologies, such as telepediatrics and artificial intelligence, now support clinical decision-making, expand access, and optimize pediatric health management. However, these advances pose ethical challenges and intensify the debate on equitable access to high-cost technologies. Key contemporary challenges include childhood obesity, vaccine hesitancy, the impact of climate change, social vulnerability, and the escalating psychological distress among children and adolescents. Perspectives for the coming decades point toward a more predictive, preventive, and personalized pediatrics, centered on the first thousand days of life, integration with public policies, and the preservation of the physician-child-family relationship as the fundamental axis of care.

Key words *Pediatrics, Advances in technology, Child health, Telemedicine, Digital health, Public health*

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Introduction

Pediatrics is the medical specialty dedicated to health promotion, prevention of diseases, diagnosis, treatment, and follow-up of growth and development of the human being from birth through late adolescence. Pediatrics emerged during the Enlightenment, influenced by the ideas of Jean Jacques Rousseau, when the child began to be viewed as a developing being – biologically vulnerable and deserving of specific protection *(Émile*, or *De l'education* – Rosseau). The 19th century saw the establishment of the first pediatric hospitals, initially in Paris with the *Hôpital des Enfants Malades* in 1802, the world's first hospital exclusively dedicated to children.[1] In Brazil, pediatrics emerged as a response to a profound social issue, the high infant mortality rates, which were intrinsically related to poverty and a lack of basic sanitation. The first major milestone was the establishment of the Chair of Pediatrics in Rio de Janeiro in 1899. From that point forward, pediatrics in Brazil has evolved based on the need to protect childhood as a vital social and biological asset for the nation.[2]

By the end of the 20th century, the pediatric epidemiological profile underwent significant shifts, with the decline in infectious diseases and a rise in chronic conditions previously reported almost exclusively in adults. The 21st century has also seen an increased detection of neurodevelopmental disorders, such as the autism spectrum disorder (ASD), and attention deficit hyperactivity disorder (ADHD), in addition to mental health conditions.[3] Within this context and the validation of the Barker's hypothesis – which emerged as early as the 1980s, posting that most chronic diseases during adulthood, both somatic and mental, originate in childhood – pediatrics has assumed even greater significance.[4] Comprehensive childcare from the very beginning, including the intrauterine life, has become paramount for preventing the leading causes of illness and death throughout the lifespan.[5,6]

Pathways and current advances

One of the most remarkable advances of contemporary pediatrics has occurred in the neonatology field. The development of neonatal intensive care units, the use of exogenous surfactant, non-invasive ventilation, prenatal corticosteroids, specialized nutritional care, alongside improved healthcare system organization – including the transfer of preterm infants to specialized centers – have contributed to increased survival rate for extremely preterm newborns. In the 1980s, the survival rate for a preterm infant with gestational age of 28 weeks was below 70%; nowadays, it reaches 94%. In the 1970s, the limit of viability was around 30-32 weeks, whereas survival is currently possible from 22-23 gestational weeks.[7]

In parallel, humanized care strategies, such as Kangaroo Care and the promotion of breastfeeding have become integrated into clinical practice. The current breastfeeding rate in Brazil is 45%, compared to only 4.7% among breastfeeding mothers in the 1980s. It is essential to highlight the fundamental role of Professor Fernando Figueira, founder of the Professor Fernando Figueira Integral Medicine Institute (IMIP). On December 3, 1974, as the Health Secretary of the State of Pernambuco, he issued the first ordinance prohibiting the unethical practice of the infant formula industry distributing powdered milk in maternity hospitals – a practice that had been driving widespread and precocious weaning. Furthermore, as the Chair of Pediatrics at the Federal University of Pernambuco (UFPE) and the Faculty of Medical Sciences, currently University of Pernambuco (UPE), Professor Fernando Figueira instituted radical shifts in the medical curriculum, mandating the intensive teaching of breastfeeding and removing courses focused on the study of infant formulas. Beyond these efforts, he translated and disseminated the book *The Baby Killer*, by the South African journalist and engineer Mike Muller, which exposed the criminal strategy of the dairy industry of promoting weaning within developing countries in favor of the indiscriminate sale of infant formula. Finally, he strengthened the human milk bank policy in throughout Brazil, establishing the first human milk bank in the North and Northeast regions, in 1986.[8]

In the field of immunization, the 21st century has been marked by the expansion of the childhood vaccination schedule, with the introduction of several vaccines that have reshaped the epidemiological profile of infectious diseases in children. Pneumococcal conjugate vaccines (PCV7, PCV10, PCV13, and PCV15/20), have reduced the incidence of pneumonia, meningitis and otitis media. The meningococcal conjugate vaccine (C, ACWY) was also introduced, followed more recently, in the 2010s, by the serogroup B vaccine. These immunizations led to a significant decline in meningitis and meningococcal sepsis. Furthermore, the rotavirus vaccine, introduced in the mid-2000s, resulted in a major reduction of hospitalizations and deaths due to diarrhea, particularly among young infants, the most vulnerable population to intestine infectious complications. In 2006, the HPV vaccine (human papillomavirus), indicated for school-aged children and adolescents, began providing a significant protection against cervical, penile, anal, and oropharyngeal cancers, as well as genital warts. Furthermore, the varicella vaccine is making this infection increasingly rare, while COVID-19 vaccine, introduced in 2021, has been crucial in preventing severe cases, MIS-C, and deaths. More

recently, the vaccines against dengue, including Brazilian-produced versions, offer a promising perspective for the control of this serious arbovirus disease. Collectively, these vaccines directly impacted the hospitalizations and deaths by infectious diseases.[9]

Genetics and precision medicine have also transformed pediatrics. Advances in genetic sequencing techniques, such as whole exome sequencing (WES), and whole genome sequencing (WGS), introduced during the 2000-2010 period, enabled the identification of rare diseases and genetic syndromes lacking a classic phenotype.[10] These techniques, applied to children with developmental delay, intellectual disability, early-onset epilepsy, and multiple congenital malformations, have provided greater diagnostic precision, even in the most complex cases. This has driven a paradigm shift: from diagnosis based solely on phenotype to an integrated genotype-phenotype diagnosis. The incorporation of technologies such as tandem mass spectrometry contributed to the early diagnosis of inborn errors of metabolism, as well as the prevention of neurological sequelae and deaths. The detection of aminoacidopathies, organic acidurias, fatty acid oxidation disorders, and certain immunodeficiencies (Severe Combined Immunodeficiency – SCID) was expanded. In addition to this, significant progress has been made in pediatric genetic counseling, with improved interpretation of genetic variants, ethical approaches, informed consent, and reproductive planning. Furthermore, the gene therapies (such as for Spinal Muscular Atrophy, approved in 2019), targeted molecular therapies (e.g., Cystic Fibrosis Transmembrane Conductance Regulator – CFTR – gene located in chromosome 7) and oncogenetics (identification of both somatic and germline mutations, risk stratification, more targeted therapies, and reduced treatment toxicity) have further advanced the field.[11]

Another significant pillar has been the recent incorporation of digital technology. Electronic health records, telepediatrics, and health monitoring apps have facilitated the access to pediatric care, particularly in remote areas. Moreover, artificial intelligence (AI) use has begun to support clinical decision-making, imaging interpretation, and risk stratification. AI is already assisting in the screening of rare and chronic diseases in children, accelerating the interpretation of laboratory tests and imaging studies. The employment of algorithms has aided both in predicting complications for certain conditions and in personalized clinical decision-making, allowing for tailored treatments. AI has also enhanced in the management and organization of pediatric services, as well as medical education and scientific research.[12,13]

Challenges

Pediatrics faces numerous challenges in this century, imposed by the demographic, technological, social, and environmental transitions. The contemporary lifestyle has led to various behavioral and dietary shifts that have significantly impacted child health. Examples include the outsourcing of childcare, excessive screen time, limited access to recreational areas, and the high intake of ultra-processed foods. Collectively, these factors have driven the rise of mental health disorders in childhood and chronic non-communicable diseases that were previously restricted to adults.[14]

As previously mentioned, advances in genetic sequencing have enabled more precise diagnosis of rare diseases. However, the challenge lies in equity: ensuring that gene therapies and high-cost drugs reach the population dependent on the public healthcare system. Whole exome sequencing (WES) and whole genome sequencing (WGS) are tests that cost over a thousand dollars each. The risk that technological innovation will widen the social inequality gap is plausible, and avoiding it will be a formidable challenge.[15]

Pediatric practice based on the new paradigm that early childhood is one of the primary determinants of health throughout the lifespan is a challenge that must be relentlessly pursued. The consolidation of DOHaD (Developmental Origins of Health and Disease) has proven the lasting impact of early-life nutrition, lack of appropriate stimuli, toxic stress, poverty, inequality, and environmental exposure. There is an urgent need for early interventions that integrate pediatrics with public health, education, and social policies.[16]

Childhood obesity, acting as a trigger for hypertension, type 2 diabetes, metabolic syndrome, and early dyslipidemia, also represents a major challenge. The nutritional transition in Brazil has demonstrated that childhood overweight and obesity is substantially higher than that of malnutrition. The pediatrician of 2026 must focus not only on the treatment but on a profound shift in family habits within an environment that is often "obesogenic". The unwavering advocacy for a healthy diet – centered on natural foods coming directly from nature, free from industrial ultra-processing – should be a legacy of the pediatrician. Similarly, ensuring access to spaces that allow children to engage in physical activities is paramount.[17]

Despite significant advances in controlling infectious diseases through immunization, the infections still represent a major cause of morbidity and mortality during childhood. Today, vaccine hesitancy – coupled with misinformation – constitutes a monumental challenge. The decline in vaccination coverage, fueled by fake news dissemination and anti-vaccine movements, threatens the resurgence of previously eliminated diseases, such as measles and polio. Restoring the trust of families in science through effective communication, in a world saturated with misinformation, remains a formidable challenge.[9]

Mental health has been impacted by the growing distance between parents and their children, driven by the outsourcing of caregiving to domestic staff or full-time schools. In addition, the excessive screen time, which provides parents with a false sense of tranquility in the moment, while further eroding the parents-child bonding. This lack of meaningful interaction appears to result in an exponential increase in cases of anxiety, depression, stress, and eating disorders among children and adolescents. The pediatrician plays a vital role in alerting parents to the significance of their presence in their children's daily lives throughout childhood.[18]

Early diagnosis of neurodevelopmental disorders, such as Autism Spectrum Disorder (ASD) and Attention – Deficit/Hyperactivity Disorder (ADHD), requires specialized expertise from the pediatrician. The early recognition of ASD, ideally before age three, has significant prognostic implications, as it can lead to substantial improvements provided that multidisciplinary treatment begins immediately. Since the diagnosis of these disorders is based strictly on clinical observation – with no "gold standard" test available to date – the role of the pediatrician is essential. Furthermore, guidance on early sensorial stimuli, such as shared reading and skin-to-skin contact is vital as these practices have been proven to significantly support neurodevelopment.[19]

Children's health is also directly impacted by the environmental crisis. Global warming has profound implications for child health, as children are the most vulnerable age group of our population. The environmental crisis increases the incidence of zoonotic diseases, as well as respiratory and allergic conditions associated with extreme heat and deterioration of air quality. Furthermore, the risk of dehydration, metabolic disorders, and nutritional impairments is heightened in contexts of food insecurity and extreme weather events. Heatwaves, floods, and wildfires favor the occurrence of respiratory and diarrheal infections, physical trauma and psychological distress, in addition to forced displacement. In this scenario, the pediatrician plays a central role in guiding families on protective measures, while also serving an advocate for the promotion of more sustainable and resilient environments for childhood.[20]

Furthermore, the pediatrician faces evolving family structures and increasing social vulnerability. The professional should be prepared to care for diverse family configurations and to identify early signs of domestic violence and neglect. Moreover, child poverty remains the primary risk factor for full development, requiring a holistic approach that encompasses health, education, and social assistance.

Finally, the ethical boundaries of technology and AI. The risks of dehumanizing care, the algorithmic bias, and the misuse of pediatric data represent significant challenges, as the balance between technological innovation and ethics, empathy, and social justice must be preserved. Accordingly, the challenge of pediatrics transcends the cure of illnesses; it is about safeguarding the future potential of humanity. This requires a professional who is, simultaneously, a highly specialized clinician and a social mediator equipped to navigate the complexities of both the environmental and digital worlds.[5,6]

Perspectives

The global population of children and adolescents surpassed 1.9 billion now in 2024, despite the significant decline in birth rates in Europe and parts of Asia and Americas, including Brazil. This drives the demand for pediatric services. Although the number of pediatricians is trending upwards in various contexts, this does not ensure equitable access, particularly in low- and middle-income countries, where scarcity remains critical. Pediatrics must be global, cooperative, and rooted in solidarity, exploring hybrid care models, telemedicine, and the strengthening of primary healthcare while prioritizing equity.[21] Technologies like telemedicine will help bridge gaps, but continuous efforts should ensure adequate human resource training.[22] Unfortunately, Brazil is currently setting a negative example in the education of young pediatricians with the reckless proliferation of medical schools lacking proper quality and serving the sole purpose of generating profits to ambitious entrepreneurs. This model may lead to iatrogenesis, as ill-trained pediatricians may themselves contribute to the onset of disease. This is a troubling prospect at a time that demands pediatricians with advanced competencies – professionals who act as educators, communicators, scientists, and advocates for children's rights. Consequently, the pediatric training requires greater proficiency in ethics, public health, data science, communication, and critical thinking, without forsaking the empathy and moral commitment that historically define the specialty.

The coming decades point toward profound transformations in pediatrics. The integration of genomics, epigenomics, and metabolomics, alongside big data and artificial intelligence is expected to steer the field toward a more predictive, preventive and personalized approach. These advancements must keep pace with shifts in science, technology, and demographic and social landscapes. However, such progress will require unwavering ethical surveillance to ensure that technology serves as a tool to support clinical decision-making, rather than a substitute for the pediatrician-child-family relationship, which remains at the core of pediatric care.[23]

Pediatrics is shifting from the treatment of disease to the promotion of healthy trajectories, from late intervention to early prevention and prediction, from an organ-centered focus to the comprehensive development of the child. The new DOHaD paradigm will serve as a cornerstone, reinforcing childhood as a critical window for adult health. Pediatrics is establishing itself, and rightly so, as the medical specialty of paramount importance for controlling chronic non-communicable diseases, the leading causes of morbidity and mortality worldwide, including Brazil. Chronic conditions such as hypertension, atherosclerosis, myocardial infarction, and stroke have no cure, they only can be managed. However, interventions in childhood, from the earliest stages of life, provide a new perspective for the primary prevention of these conditions.[24]

The primary focus of pediatrics must be centered on the first 1,000 days, with early interventions starting in intrauterine life, focusing on maternal-fetal nutrition, the continuity of exclusive breastfeeding, in the reduction of ultra-processed food consumption, and adequate sensorial stimuli. Furthermore, it must prioritize fostering a strong mother-child dyad bond, ensuring parental responsiveness, and mitigating toxic stress. Pediatrics requires structural integration with education, social assistance, and public policies.[25]

Neonatology must focus on quality of life, ensuring that, alongside survival of extremely preterm infants, there is a full neurodevelopment with preservation of cognitive function and long-term well-being. Deeper ethical discussions about the limits of viability, the rights of the fetus and the preterm infant, and the boundaries of intervention, should lead to more mature and shared decision-making approaches.[7]

Perspectives on mental health point toward a pediatric practice that is increasingly preventive and integrated with neurodevelopment. Psychological distress must be systematically screened by the pediatrician, through careful observation and listening for the subtle signs of suffering, behavioral changes, school and relationship difficulties. This task also involves preventive guidance for parents regarding attachment, family life, routines, boundaries, sleep, play, physical activity, screen time, and affective communication. All of these efforts should start during the first 1,000 days of life, including pediatric prenatal visits aimed at promoting healthy emotional environments. Furthermore, care must be rooted in secure bonding and positive parenting, which requires closer interdisciplinary collaboration between the pediatrician, the family, schools, child psychiatrists, and psychologists to identify of risk factors (violence, neglect, poverty, chronic disease, parental distress) and activate supportive networks.[26]

Finally, pediatrics will play a pivotal role in environmental health. The impacts of climate change, pollution, food insecurity, and the exposure to environmental toxins, place all children at risk – first and foremost – due to their heightened vulnerability and the irreversible damage caused by the failure to reach their full growth and development potential. It will be the pediatrician's responsibility to identify environmental risks early, guiding both the families and public authorities on these threats. Pediatrics should reinforce the inseparability of child health, social justice, and environmental sustainability.

Final considerations

Twenty-first-century pediatrics has consolidated extraordinary advances that have expanded survival and improved the quality of life for children and adolescents. However, this progress coexists with complex challenges related to social inequalities, emerging epidemiological demands, professional training, and the ethical boundaries of technological integration. The future of pediatrics will depend on the ability to integrate scientific innovation, health equity, and humanized care, recognizing childhood as the decisive period for life-course health. The strengthening of public policies, intersectoral action, and the pediatrician's ethical commitment will be instrumental in transforming technical advances into sustainable and lasting benefits for future generations.

Author's contribution

The author conceptualized the article and declares no conflicts of interest.

Data availability

All datasets supporting the results of this study are included in the article.

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