Review

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Quo vadis neonatologia? Where is neonatology heading in the 21st century?

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Abstract

Introduction: This comprehensive narrative review examines current paradigms, emerging trends, and future directions in neonatology through systematic analysis of contemporary literature, clinical practice patterns, and expert consensus. We synthesized evidence from recent publications, international guidelines, and clinical innovations to identify key transformation areas.

Content: Several critical areas are reshaping neonatology. Gestational age has emerged as a lifelong health determinant with implications extending far beyond the neonatal period, affecting cardiovascular, metabolic, and neurodevelopmental outcomes throughout life. Global disparities in neonatal care remain unconscionably large, with survival rates for 28-week infants exceeding 90 % in high-income countries while similar infants in low-resource settings often die from preventable causes. Artificial intelligence applications are revolutionizing predictive analytics, real-time monitoring, and decision support systems, though implementation requires careful attention to bias, transparency, and human oversight. The neonatal microbiome's crucial role in immune development and long-term health has prompted interventions targeting healthy colonization. Salutogenic approaches emphasizing health promotion rather than disease treatment are gaining recognition. Most significantly, the systematic marginalization of mothers in neonatal care is being challenged, with growing recognition of the mother-infant dyad as the fundamental unit of care.

Summary and Outlook: Future neonatal care must balance technological advancement with humanistic values, addressing global disparities while maintaining scientific rigor. Success requires committing to global health equity, embracing ethical complexity at viability margins, recognizing maternal centrality, thoughtfully integrating emerging technologies, implementing salutogenic principles, and adopting lifelong health perspectives. The field's future depends on interdisciplinary collaboration, ethical reflection, and unwavering commitment to ensuring every newborn receives compassionate, high-quality care.

Keywords: neonatology; gestational age; global health; artificial intelligence; salutogenesis; mother-infant dyad

Introduction

Neonatology emerged as a distinct medical specialty upon recognizing that newborns are physiologically unique beings, fundamentally different from older infants – just as pediatrics developed from understanding that children are not miniature adults [1]. The neonatal period represents one of the most vulnerable phases of human existence, with the neonate undergoing extraordinary physiological transition from the protected uterine environment to the challenging terrestrial world. The newborn is, essentially, a "born fetus", suddenly navigating an environment characterized by gravity, atmospheric pressure, direct oxygen exposure, and microbial colonization [2, 3].

Contemporary neonatology faces unprecedented challenges extending beyond traditional intensive care boundaries. The field must address questions unimaginable decades ago: How do we optimize outcomes for infants at extreme viability limits? How do we address growing global disparities in neonatal care? What role should artificial intelligence (AI) play in clinical decision-making?

This review explores current state and future directions of neonatology, examining key challenges including lifelong

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gestational age implications, clinical terminology inconsistencies, global care inequalities, and the emergence of salutogenic frameworks and AI applications. Importantly, we examine the underrecognized but central role of the mother in neonatal outcomes–marginalized despite overwhelming evidence of its importance [4].

Historical evolution

Neonatology emerged as a distinct specialty in the mid-20th century, driven by revolutionary advances in neonatal ventilation, monitoring systems, and nutritional support [2]. The pivotal development of perinatal regionalization systems in the 1970s represented a fundamental healthcare delivery shift, stratifying risk and centralizing complex cases in tertiary centers [5–8]. While dramatically successful in high-income countries, this model remains difficult to replicate in low-resource settings due to infrastructure, workforce, and funding limitations [9, 10].

Today, neonates are recognized not as small infants or ex-utero fetuses, but as unique transitional beings requiring precision-based care approaches. This recognition has led to subspecialized areas including neonatal neurology, cardiology, and surgery, while technological advances have paralleled our understanding of developmental biology and long-term consequences of early-life experiences [11].

Gestational age: a lifelong health determinant

Gestational age (GA) stands as one of the most powerful predictors of both immediate neonatal outcomes and lifelong health trajectories [12]. Preterm infants face immediate risks including respiratory distress, hemorrhage, and sepsis, with implications extending far beyond acute complications to include cerebral palsy, intellectual disability, and behavioral disorders. Emerging evidence reveals that even “early-term” infants (37–38 weeks) face increased long-term risks compared to those born at optimal 39–40 weeks [13–17].

Clinical GA management is complicated by persistent terminology confusion. Obstetricians typically use “running weeks” (36 + 5 weeks represents the 37th week), while neonatol” ogists rely on “completed weeks” (36 + 5 remains 36 weeks). These distinctions significantly impact critical decisions including corticosteroid timing, cesarean delivery decisions, and Neonatal Intensive Care (NICU) admission thresholds [18–20].

Recognition of GA as a lifelong biomarker has led to proposals for incorporating GA into adult medical records, developing GA-adjusted reference ranges, and using this information for lifelong screening and risk assessment strategies.

Common neonatal conditions and global disparities

Several conditions dominate neonatal care due to frequency and severity [21–27]. Preterm birth remains the leading cause of neonatal mortality worldwide, with complications including infections, respiratory distress syndrome, patent ductus arteriosus, and necrotizing enterocolitis. Long-term consequences extend to increased cardiovascular disease, metabolic syndrome, and reduced fertility risks in adulthood.

Neonatal infections continue representing major morbidity causes, particularly in settings lacking infection control or antimicrobial access. The vulnerability reflects immature immune systems and frequent invasive procedure exposure [28–30].

Despite overall progress, global disparities remain unconscionably large. According to WHO, nearly half of under-5 deaths occur during the neonatal period, mostly in low-income countries from preventable causes [31, 32]. Essential interventions – thermal regulation, clean birth practices, breastfeeding support, basic resuscitation – remain inconsistently available. In high-income countries, 28-week infant survival exceeds 90 %, while similar infants in low-income settings often die from lack of basic supportive care [33].

Ethical complexities at viability margins

Viability refers to the gestational age at which a fetus has a reasonable chance of survival outside the uterus with appropriate medical support. Over the last few decades the threshold of viability has historically been considered around 24 weeks gestation, though this varies significantly based on multiple factors including healthcare setting, available resources, fetal lung maturity, antenatal corticosteroid administration, maternal conditions, intrauterine growth, and the presence of major congenital anomalies. The availability of exogenous surfactant therapy, advanced mechanical ventilation, and specialized neonatal intensive care significantly influences survival outcomes at these early gestational ages.

Advances have pushed viability boundaries in high-income countries to 22–23 weeks gestation, creating unprecedented ethical challenges [34]. Survival at these margins often involves significant neurodevelopmental disability risks and reduced quality of life. Prognostic uncertainty, varying legal frameworks, and cultural differences complicate decision-making [35–37].

Healthcare providers experience moral distress when feeling constrained from ethically appropriate actions. Addressing these challenges requires robust ethics consultation, interdisciplinary support, and shared decision-making frameworks respecting family values while maintaining professional integrity.

Family-centered care and parental engagement

Active parental involvement represents both ethical principle and evidence-based strategy for improving outcomes [38, 39]. Kangaroo Mother Care (KMC), emphasizing continuous skin-to-skin contact, demonstrates numerous benefits including improved thermal regulation, breastfeeding success, weight gain, and neurodevelopmental outcomes [40, 41]. Despite robust evidence, implementation remains inconsistent due to institutional policies prioritizing technology over human contact. The Baby-Friendly Hospital Initiative (BFHI), launched by the World Health Organization (WHO) and UNICEF in 1991 and updated in 2018 to protect, promote, and support breastfeeding in healthcare settings, has been predominantly implemented in high-income countries. In contrast, its implementation in low-income countries remains limited, leaving many mothers and infants without adequate support for successful breastfeeding, which may negatively affect their health [42].

Effective engagement requires transparent communication, trust-building, and recognition of parental expertise. Single-family room designs facilitating privacy and parent-infant interaction show improved outcomes compared to traditional open-bay designs.

Microbiome and early life programming

The maternal and neonatal microbiome play crucial roles in immune development, metabolic programming, and neurological function [43–49]. Cesarean delivery, antibiotic exposure, and formula feeding contribute to dysbiosis, associated with increased asthma, allergies, diabetes, and neurodevelopmental disorder risks. Understanding microbiome importance has led to interventions including vaginal seeding, probiotic supplementation, and judicious antibiotic use, though implementation requires careful risk-benefit consideration.

Salutogenesis and health promotion

Traditional pathogenesis-focused approaches, while successful in reducing mortality, may be insufficient for optimizing long-term outcomes. Salutogenesis (from Latin ‘salus’=health + Greek ‘genesis’=origin) literally means “the origins of health.” Salutogenesis seeks to identify factors supporting health and resilience rather than simply treating disease [50–52]. In neonatology, this emphasizes minimizing unnecessary interventions, promoting physiological processes, supporting bonding, and creating healing environments. Implementation includes developmental care, family-centered models, and environmental modifications supporting neurological maturation.

Rare diseases and genetic advances

The neonatal period presents a unique window of opportunity for the recognition and management of rare diseases–conditions that, by the European definition, affect fewer than five in 10,000 individuals in the general population [53, 54]. Intriguingly, many of the conditions encountered in the NICU meet this criterion, suggesting that rare diseases may, paradoxically, be relatively common within neonatal medicine [55–57].

Timely diagnosis during the neonatal period can be life-saving and significantly improve long-term outcomes which has been perceived useful by parents [58]. Advances in genomic technologies, particularly next-generation sequencing, have made it possible to identify the molecular basis of many rare disorders shortly after birth [59]. Early diagnosis allows for the initiation of targeted therapies, genetic counseling for families, and individualized care strategies that may alter the natural course of the disease and improve survival [60].

Furthermore, incorporating rare diseases into neonatal screening programs and promoting clinical suspicion among neonatologists are essential steps toward reducing diagnostic delays, which remain a major challenge [61]. A greater awareness of the prevalence of rare diseases in the

NICU setting–particularly metabolic, neuromuscular, and immunological conditions–can lead to earlier recognition, better prognostication, and more effective management strategies [62]. This process may be improved by using artificial intelligence [63].

As neonatal care continues to evolve, integrating rare disease awareness and diagnostic pathways into standard practice may be one of the most impactful advances for a subset of patients whose conditions, while individually rare, collectively represent a significant clinical burden.

Artificial intelligence: promise and challenges

AI integration represents transformative development, offering unprecedented outcome improvement opportunities while raising safety, equity, and human judgment questions [64–68]. Applications span predictive analytics for complication identification, real-time monitoring, and decision support systems. However, implementation must address algorithm bias risks, transparency requirements, and automation bias potential. Healthcare organizations must ensure data privacy and security while maintaining human clinical expertise primacy.

The central role of mothers

Contemporary neonatal care systematically marginalizes mothers despite overwhelming evidence of their biological, psychological, and social indispensability [69, 70]. The mother-infant dyad should be recognized as the fundamental care unit. Routine post-birth separation disrupts evolutionarily conserved processes occurring when both are primed for bonding. Breastfeeding provides optimal nutrition, immune protection, and physiological regulation, with composition dynamically responding to infant needs.

Institutional practices often create breastfeeding barriers through separation, inflexible schedules, and inadequate support. Mothers actively involved in care report higher confidence and lower anxiety, while excluded mothers experience helplessness and traumatic stress. International models in high-income countries like Newborn Individualized Care and Assessment Program (NIDCAP) and Family Integrated Care (FICare) demonstrate improved outcomes when recognizing parents as primary caregivers rather than visitors.

Future directions

Several emerging paradigms will shape neonatology's future. Precision medicine approaches toward individualized care based on genetic and metabolic markers represent fundamental shifts from uniform protocols. Pharmacogenomics has particular relevance where drug responses vary by genetic factors and gestational age.

Regenerative medicine, including stem cell therapy and tissue engineering, offers potential for repairing damaged organs, potentially transforming conditions like brain damage, bronchopulmonary dysplasia and necrotizing enterocolitis. Digital health technologies enable specialized care extension beyond hospitals through remote monitoring and telemedicine platforms.

Global health integration drives scalable approach development for resource-limited settings, including low-cost device development, task-shifting strategies, and innovative financing mechanisms. "Frugal innovation" concepts–developing effective, affordable solutions using local resources–are particularly relevant for expanding quality care access even in low-income settings [71].

Conclusions

Neonatology stands at a critical evolutionary juncture. The field has achieved remarkable survival improvements for vulnerable infants, but success has revealed new challenges extending beyond traditional medical concerns. The future requires addressing several key imperatives simultaneously:

First, committing to addressing unconscionable global outcome disparities through increased resources, improved systems, and fundamental equity commitment. Second, embracing ethical decision-making complexity while developing sophisticated family and provider support frameworks. Third, recognizing and supporting the central family role, particularly mothers, requiring fundamental care organization changes toward genuine family-centered approaches.

Fourth, thoughtfully integrating emerging technologies while maintaining human values focus. Technology should enhance rather than replace human connection and clinical judgment. Fifth, embracing salutogenic approaches promoting health and resilience rather than simply treating disease. Finally, committing to lifelong health perspectives, recognizing neonatal interventions have entire lifespan implications.

Success depends on neonatal community ability to collaborate across disciplines, institutions, and boundaries addressing shared challenges. Most importantly, the future must be guided by unwavering commitment to the principle that every newborn deserves compassionate, high-quality care respecting their dignity and potential.

Quo vadis neonatologia? The field heads toward a future demanding not only scientific excellence and technological innovation but also moral courage, ethical reflection, and deep commitment to human values making medicine a healing profession. Today's choices will determine whether neonatology fulfills its potential to create a world where every newborn has the opportunity to thrive.

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