

Infant Heart Development, Attachment, and Long-Term Cardiovascular Risk: From Congenital Disease to IoT-Based Predictions

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Abstract:

This review explores the multifaceted relationship among infant heart development, early attachment experiences, and lifelong cardiovascular risks, shaped by genetic, environmental, and technological factors. The primary objective is to synthesise current global research on how congenital heart disease (CHD), parent-infant bonding, and early biological regulation interact to influence long-term cardiac health. Infant cardiac maturation depends on precise genetic programming, but it is susceptible to prenatal conditions, epigenetic modifications, perinatal inflammation, and preterm birth. Beyond structural development, early attachment plays a significant role in modulating stress physiology and autonomic balance, both of which have lasting impacts on cardiovascular function. Secure attachment is increasingly recognised as a protective factor that can buffer the effects of early biological vulnerabilities associated with cardiac disease. At a global level, CHD remains one of the most prevalent congenital anomalies, and advancing neonatal care has transformed survival outcomes. However, this improved survival has highlighted the growing burden of heart failure and other chronic complications later in life. Current clinical trials across continents are examining new biomarkers, early detection techniques, and interventions that target both cardiac repair and developmental adaptation. Parallel to these medical advances, digital health innovations are dramatically reshaping paediatric cardiology. Internet of Things (IoT)-based technologies—such as biosensing wearables, wireless monitors, and cloud-supported data analytics—are creating new possibilities for continuous monitoring and predictive modelling of infant cardiac health. These tools enable early detection of abnormalities, assist in personalised care planning, and may help forecast long-term heart failure risks by integrating physiological, behavioural, and environmental data. This interdisciplinary review calls for closer collaboration among cardiologists, developmental scientists, and data engineers to develop equitable, ethically responsible predictive systems. By linking traditional clinical understanding with emerging digital frameworks, it emphasises a holistic perspective on the prevention and management of cardiovascular disease from infancy through adulthood.

Keywords: Infant cardiac development, congenital heart disease, attachment, heart failure, IoT, epigenetics, inflammation, preterm birth.

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1. Introduction

Congenital heart disease (CHD) represents one of the most prevalent and significant congenital anomalies worldwide, imposing substantial morbidity and mortality, particularly in infants and young children. According to the 2025 Global Burden of Disease (GBD) study, over 4.18 million children under five years suffer from CHD globally, with prevalence slightly increasing by 3.4% since 1990 despite advances in medical care. Moreover, CHD remains the leading cause of death from congenital anomalies in children under five, accounting for over 200,000 deaths annually, predominantly in low- and middle-income countries where diagnostic and therapeutic disparities prevail¹. Preterm birth further adds complexity to this burden, as infants born prematurely exhibit an increased vulnerability to cardiovascular complications in infancy and later life, highlighted by a growing body of epidemiological and clinical research. The impact of CHD and prematurity on infant development, neurodevelopmental trajectories and autonomic regulation². Infant-parent attachment quality emerges as a crucial psychosocial factor influencing infant resilience, autonomic function, and potentially cardiac recovery. Infants with CHD often face disrupted bonding processes due to prolonged hospitalisations and medical procedures, which may adversely affect emotional regulation and long-term cardiovascular health through mechanisms still under active investigation. Recent advancements in healthcare technology, particularly the integration of Internet of Things (IoT) devices and artificial intelligence (AI), offer exciting opportunities for early detection, continuous monitoring, and predictive analytics in paediatric cardiology. Wearable sensors and telemedicine platforms enable real-time, remote monitoring of infant cardiac activity, potentially providing access to care and personalisation³. These innovations provide a complementary approach alongside traditional clinical management and psychosocial support, underscoring the need for a multidisciplinary framework that combines cardiology, developmental psychology, and technology to address the complex challenges faced by infants with CHD and at high cardiovascular risk⁴. This review paper aims to synthesise current evidence across the clinical, psychological, and technological domains to present a comprehensive global perspective on infant heart development, attachment processes, and long-term cardiovascular risk⁵. Emphasis is placed on exploring how emerging IoT and AI tools can improve early diagnosis and prognostication, ultimately enhancing survival and neurodevelopmental outcomes worldwide⁶. By integrating multiple disciplines, the review highlights pathways for holistic interventions and proposes future research directions addressing gaps in global health equity and multidisciplinary collaboration⁷.

2. Aim and Objectives

The primary aim of this literature review is to provide a detailed, integrative synthesis of contemporary global research concerning infant heart development, focusing on first, the biological and clinical features of congenital heart disease (CHD); second, the influence of parent-infant attachment on infant cardiac and neurodevelopmental outcomes; and third, the potential of Internet of Things (IoT) and artificial intelligence (AI) technologies for improving early cardiovascular risk prediction and monitoring in infancy⁸. Specific objectives include delineating the epidemiological trends, global burden, and disparities in CHD and preterm birth affecting infant cardiac health⁹. To examine the stages and

mechanisms of normal and pathological infant heart development, including genetic and environmental influences on CHD. To analyse the role of early parent-infant attachment quality and psychosocial factors in modulating infant stress responses and cardiac outcomes, particularly after surgery or medical interventions¹⁰. To review advancements in IoT-enabled wearable devices, remote monitoring platforms, and AI-based predictive models that enable proactive infant cardiac care. To discuss the implementation challenges, ethical considerations, and future directions for integrating biological, psychological, and technological approaches into clinical practice and global health policies. By addressing these interconnected dimensions, the review aims to inform clinicians, researchers, and policymakers about the importance of multidisciplinary strategies to reduce morbidity and mortality from infant cardiovascular disorders while promoting optimal neurodevelopment and quality of life globally¹¹. Table 1

Table 1. Comparison of the Present Review with Existing Review Papers

Sr. No.	Ref. (Year)	Review Methodology	Contribution	Significant Difference from This Review
1	62 (2020)	Systematic review and meta-analysis	Evaluates the effectiveness and safety of pharmacological interventions for retained placenta.	Does not consider AI-based approaches or sensing devices; focuses only on a single maternal condition (retained placenta).
2	63 (2019)	Seminal review	Identifies key characteristics and drivers influencing the adoption of artificial neural networks (ANNs) in healthcare organisational decision-making.	Does not address maternal or infant healthcare; sensing technologies are not included.
3	64 (2021)	Systematic review	Reviews the role of AI and ML, including deep learning, in improving pregnancy-related patient care and outcomes.	Infant health issues and sensing-based healthcare systems are not considered.
4	65 (2020)	Systematic review	Provides an evidence map of machine learning applications in paediatrics and adolescent medicine.	Maternal health is not addressed; sensing-based remote patient monitoring is not included.
5	65 (2020)	Systematic review	Summarises studies using computerised decision support systems (CDS) and ML for childhood obesity management.	Limited to childhood obesity; maternal health and broader infant healthcare are excluded.
6	63 (2019)	Systematic review	Presents a systematic literature review protocol on the role of	Maternal and infant healthcare applications

			mobile computing in IoT-based healthcare applications.	are not specifically investigated.
7	66 (2021)	Non-systematic comprehensive survey	Reviews AI-based prediction, diagnosis, early identification, and monitoring of women across pregnancy, labour, and postpartum stages.	Infant healthcare is not addressed, nor are sensor networks for maternal–infant monitoring.
8	67 (2018)	Comprehensive review	Discusses medical applications, ethical issues, and standardisation challenges in 5G-enabled e-health systems.	AI is not the primary focus, and pregnancy- or infant-specific healthcare problems are not targeted.

3. Methodology

This literature review employed a systematic approach to identify and synthesise relevant studies published between 2010 and 2025 across multiple disciplines, including cardiology, developmental psychology, neonatology, and digital health. Major electronic databases such as PubMed, including C, ScienceDirect, Google Scholar, and IEEE Xplore were searched using a combination of keywords and Boolean operators¹². Key search terms included “infant heart development,” “congenital heart disease,” “parent-infant attachment,” “cardiovascular risk,” “prematurity,” “Internet of Things,” “artificial intelligence in cardiology,” “remote cardiac monitoring,” and “neurodevelopmental outcomes¹³.” Inclusion criteria were: Peer-reviewed original research articles, reviews, meta-analyses, clinical trials, and technological evaluations¹⁴. Studies addressing infant or neonatal populations related explicitly to cardiac development, CHD diagnosis or treatment, attachment and psychosocial factors, or IoT/AI technologies in paediatric cardiology¹⁵. Publications in English from 2010 onwards will capture the most recent advances and data. Exclusion criteria comprised: Studies focusing solely on adult cardiac disease without infant or developmental focus. Articles lacking primary data or sufficient methodological detail, such as editorials or opinion pieces without evidence¹⁶. Grey literature, conference abstracts without full text, or non-peer-reviewed sources. The study selection process involved initial screening of titles and abstracts, followed by full-text review for eligibility and relevance¹⁷. Data extraction covered study design, population characteristics, key findings related to heart development, attachment, or technological innovation, and reported limitations¹⁸. A narrative synthesis approach was adopted due to the interdisciplinary and heterogeneous nature of the literature, integrating clinical, psychosocial, and technological evidence¹⁹. Limitations of this methodology include potential publication bias favouring studies from high-income countries with greater access to advanced technology, possible language bias excluding non-English papers, and variability in diagnostic criteria and technological platforms across studies²⁰. While efforts were made to gather comprehensive global data, disparities in regional reporting and screening methods introduce challenges to definitive prevalence comparisons. Nevertheless, this approach provides a robust framework for exploring multifactorial dimensions influencing infant cardiovascular health and advancing health and prognostic innovations²¹.

4. Global Epidemiology and Burden of Infant Heart Disease and Preterm Birth

Congenital heart disease remains a leading global cause of infant morbidity and mortality.

The latest Global Burden of Disease (GBD) data from 2021 estimate that over 4.18 million children under five are affected worldwide, with a childhood prevalence of nearly 6.4 per 1000 live births. Over the past three decades, CHD-associated mortality decreased by 56.2% globally due to medical advances, but persists disproportionately among low- and middle-income countries, particularly in South Asia and Africa²². High mortality and disability-adjusted life years (DALYs) continue in regions with limited access to early diagnosis and paediatric cardiac surgery. Significant regional disparities exist, with low and low-middle-income Demographic Index (SDI) countries exhibiting the highest prevalence and mortality rates²³. For instance, India reports the most considerable burden of CHD cases, while Afghanistan experiences the highest mortality rates.²⁴ Conversely, high-income nations demonstrate markedly lower mortality and improved survival owing to robust neonatal screening, surgical infrastructure, and long-term care²⁵. These disparities reflect inequities in prenatal diagnosis, healthcare availability, and trial availability. Preterm birth further complicates infant cardiovascular outcomes²⁶. Estimates indicate that 10% of global births occur prematurely, many of whom face additional risks from underdeveloped cardiac and pulmonary systems²⁷. Prematurity is independently associated with increased incidence of congenital and acquired heart defects, arrhythmias, and susceptibility to heart failure later in life²⁸. The combined burden of CHD and prematurity exacerbates neurodevelopmental delays and long-term health risks, justifying targeted interventions in neonatal intensive care units (NICUs) as well as community health settings²⁹. Early screening efforts, such as pulse oximetry, fetal echocardiography, and newborn cardiac ultrasound, have improved detection rates but remain underutilised in resource-poor settings due to costs, equipment shortages, and specialist shortages³⁰. We limit timely interventions and contribute to late presentations with advanced heart failure or irreversible damage. Policymakers and global health initiatives emphasise strengthening regional healthcare systems, expanding newborn screening, and enhancing surgical capacity to address this burden equitably³¹. Figure 1

Global Prevalence of Heart Disease

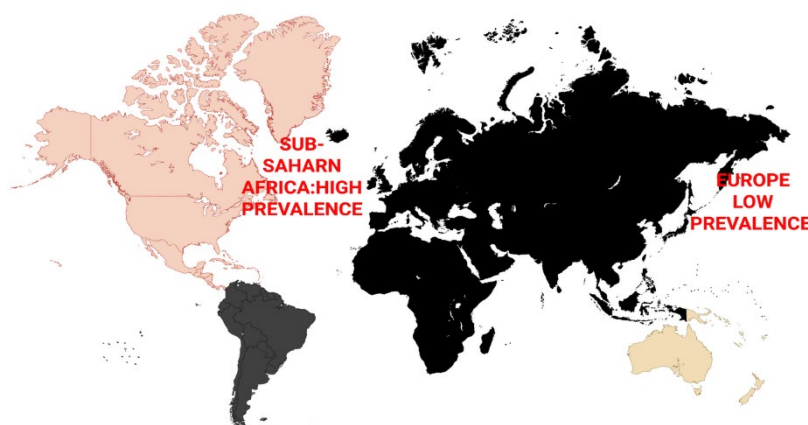


Figure 1. The map illustrates regional differences in CHD prevalence rates, with higher rates (>5%) in Sub-Saharan Africa, Latin America, and parts of Asia, and lower rates (0–2%) across Europe and Oceania. Data highlights global disparities in diagnostic access and healthcare infrastructure.

5. Infant Heart Development: Biological and Clinical Perspectives

Normal cardiac development is a sequential, tightly regulated process that commences in embryogenesis and culminates in a structurally and functionally competent heart at birth.

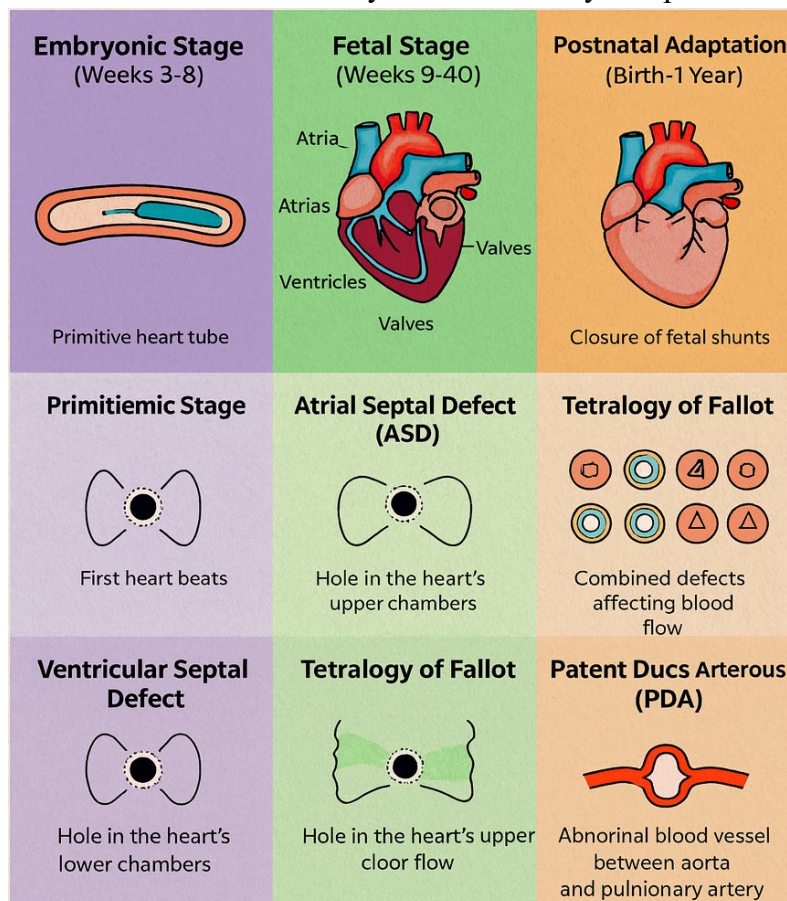


Figure 2: cardiac development proceeds from the embryonic formation of the primitive heart tube through fetal morphogenesis to postnatal circulatory adaptation. Disruptions during these stages lead to defects such as ASD, VSD, and Tetralogy of Fallot.

Early differentiation of cardiac progenitor cells, cardiomyocyte proliferation, and morphogenesis establishes essential structures, including atria, ventricles, valves, and outflow tracts. Molecular signalling pathways such as Notch, Wnt, BMP, and Hedgehog pathways orchestrate these events, and perturbations lead to diverse congenital disabilities³². Shown Figure 2. Common congenital heart defects include septal defects (atrial and ventricular), patent ductus arteriosus, Tetralogy of Fallot, coarctation of the aorta, and transposition of the great arteries. Genetic mutations, chromosomal anomalies, and environmental exposures (maternal diabetes, infections, medications) contribute to the aetiology of CHD³³. Advances in prenatal imaging especially fetal echocardiography and MRI enable earlier and more precise detection, facilitating perinatal planning for high-risk deliveries³⁴. Postnatal cardiac physiology undergoes a dramatic transition from fetal circulation patterns to independent systemic and pulmonary circuits. Neonates, especially preterm infants, exhibit limited myocardial reserve and distinct autonomic regulation, rendering them vulnerable to hypoxia, ischemia, and hemodynamic instability when affected by

CHD. Understanding these physiological differences guides critical care strategies and surgical timing to minimise complications³⁵.

6. Parent-Infant Attachment and Psychosocial Impact on Cardiac Outcomes

Attachment theory elucidates the dynamic interplay between infant emotional regulation and caregiver responsiveness, highlighting the foundational role of secure parent-infant bonds in healthy neurodevelopment³⁶. In infants with CHD, early medical interventions, prolonged hospitalisations, and caregiver stress compromise opportunities for consistent, sensitive caregiving, disrupting attachment processes³⁷. Secure attachment promotes optimal autonomic regulation, evidenced by balanced heart rate variability, which is critical for cardiac recovery and resilience post-surgery³⁸.

Conversely, insecure or disrupted attachment correlates with heightened stress responses and altered hypothalamic-pituitary-adrenal axis functioning³⁹. Studies document increased parental anxiety and depressive symptoms following CHD diagnosis, further impacting infant outcomes. Psychosocial interventions, including familiar care, kangaroo mother care, and clinician-facilitated bonding sessions, have demonstrated improvements in infant parasympathetic tone and reduced hospital length of stay⁴⁰⁻⁴¹. These approaches underscore the need to integrate psychological support into cardiac care to enhance recovery and long-term health⁴².

7. Long-Term Cardiovascular Risks and Outcomes in CHD Survivors

Improvements in survival have resulted in increasing adult congenital heart disease (ACHD) populations, necessitating lifelong surveillance to manage risks such as heart failure, arrhythmias, pulmonary hypertension, and re-intervention⁴³. Clinical guidelines recommend regular cardiac imaging, electrocardiographic monitoring, and exercise capacity assessments to identify early signs of deterioration⁴⁴. Longitudinal cohort studies reveal that earlier cardiac function, neurodevelopment, and psychosocial environment influence adult morbidity and quality of life⁴⁵. Behavioural factors like physical inactivity, obesity, and smoking exacerbate cardiovascular risk in this population⁴⁶. Neurocognitive impairments and psychosocial adjustment challenges further compromise long-term outcomes and functional independence⁴⁷.

8. Advances in IoT and AI Technologies for Infant Cardiac Monitoring and Prediction

The integration of IoT and AI technologies into paediatric cardiology offers transformative potential for infant heart care⁴⁸. Wearable biosensors capable of continuously measuring heart rate, rhythm, oxygen saturation, and respiratory rate are increasingly miniaturised and infant-friendly, allowing real-time remote monitoring beyond hospital settings⁴⁹. Machine learning algorithms and deep neural networks enhance predictive capacity by analysing large, multidimensional data streams to detect early signs of cardiac distress or arrhythmias. Pilot clinical trials utilising IoT-enabled platforms demonstrate improved early warning systems and better parental engagement through smartphone interfaces⁵⁰. See Figure 3 Despite the promise, challenges remain regarding data privacy, device validation, clinician training, and healthcare integration. Equitable access to these technologies in low-resource settings depends on cost reduction, infrastructure development, and policy support. Ethical frameworks addressing consent and data security are paramount to responsible use⁵¹.

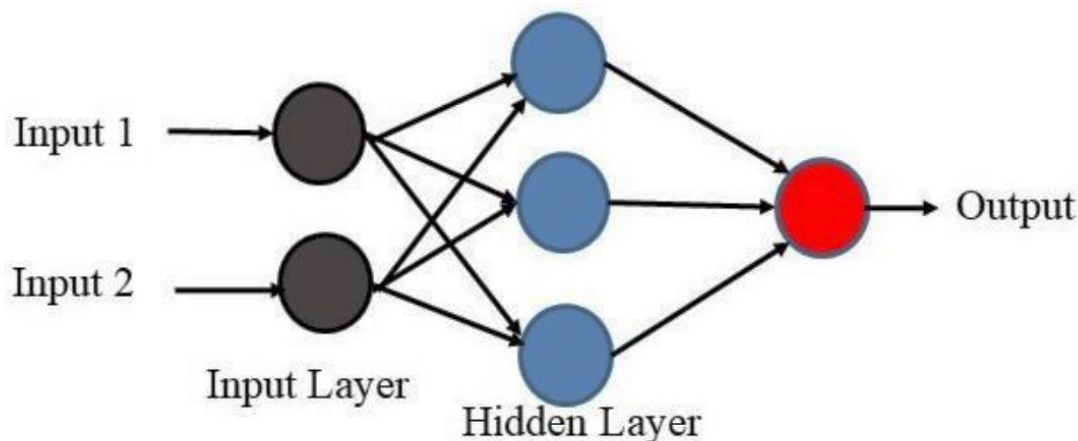


Figure 3: Simple Neural Network

9. Discussion

The review highlights that advances in infant cardiovascular health depend on a multidisciplinary approach combining biological, psychosocial, and technological innovations⁵². While clinical and surgical interventions remain foundational, addressing attachment and parental mental health is equally critical to optimising cardiac recovery and neurodevelopment⁵³⁻⁵⁴. Technological innovations, particularly IoT and AI, hold potential for reducing inequalities by extending surveillance and predictive analytics to remote and underserved areas⁵⁵. Policymakers must prioritise investments in neonatal screening programs, psychosocial support, and digital health infrastructure to translate these advances globally⁵⁶. Ethical considerations, particularly around data privacy and equitable access, require ongoing dialogue among clinicians, families, technologists, and regulators. Bridging research gaps through large-scale, culturally diverse cohort studies and interprofessional collaborations will drive more effective, inclusive infant cardiac care worldwide⁵⁷.

10. Future Scope and Recommendations

Future research should prioritise longitudinal, multicentre studies that integrate biological, psychological, and technological data streams to better understand the complex interactions that affect infant cardiac outcomes. The development of standardised protocols that combine clinical screening, psychosocial assessment, and IoT-enabled monitoring will strengthen early detection and personalised interventions⁵⁸. Expansion of the family's psychosocial programs designed for caregivers of infants with CHD is critical to optimise attachment and resilience. Policy reforms are needed to support equitable access to digital health tools globally, including subsidies, infrastructure development, and training programs⁵⁹. Ethical frameworks for data privacy, informed consent, and surveillance transparency must evolve alongside technology to safeguard vulnerable populations. Multi-sector collaborations across cardiology, psychology, engineering, and public health will accelerate innovation and implementation. Finally, investment in global data-sharing platforms can enhance epidemiological surveillance, support comparative effectiveness research, and guide resource allocation to reduce disparities in infant cardiovascular care worldwide⁶⁰.

11. Conclusion

Infant heart development and long-term cardiovascular risk in congenital heart disease represent complex interwoven challenges demanding integrated clinical, psychological, and technological solutions. Despite marked improvements in survival, disparities in global outcomes persist, disproportionately affecting low-resource regions. Parent-infant attachment quality emerges as a modifiable psychosocial determinant of infant cardiac resilience and recovery, underscoring the need for family care models. IoT and AI technologies are redefining the paradigms for early diagnosis and continuous monitoring, offering personalised, real-time management opportunities that complement traditional healthcare delivery. These tools have the potential to democratise access to specialised cardiac care if implemented thoughtfully, with ethical safeguards. Collectively, these integrated approaches promise to enhance survival, neurodevelopment, and quality of life for infants globally. This review advocates for global collaboration, policy reform, and sustained investment in multidisciplinary research and digital health infrastructure to meet the needs of vulnerable infant populations worldwide.

References:

1. Almurashi, A. M., Rodriguez, E., & Garg, S. K. (2023). Emerging diabetes technologies: Continuous glucose monitors and artificial pancreases. *Journal of the Indian Institute of Sciences*, 103, 205–230. <https://doi.org/10.1007/s41745-022-00348-3>
2. Areia, C., King, E., Ede, J., Young, L., Tarassenko, L., Watkinson, P., & Vollam, S. (2021). Experiences of current vital signs monitoring practices and views of wearable monitoring: A qualitative study in patients and nurses. *Journal of Advanced Nursing*, 78(3), 810–822. <https://doi.org/10.1111/jan.15055>
3. Atta, M. H. R., Shaala, R. S., Mousa, E. F. S., El-Monshed, A. H., Fatah, N. K. A. E., & Khalil, M. I. M. (2024). Exploring the mediating influence of acceptance of change: Gerontechnology acceptance, mental well-being, and urban–rural disparities among older adults. *Geriatric Nursing*, 58, 324–335. <https://doi.org/10.1016/j.gerinurse.2024.06.006>
4. Badeaux, R. (2024, August 29). *Innovative new technology helps seniors age in place*. University of California. <https://www.universityofcalifornia.edu/news/innovative-new-technology-helps-seniors-age-place>
5. Balasubramanian, G. V., Beaney, P., & Chambers, R. (2021). Digital personal assistants as assistive technology for health and wellbeing. *BMC Geriatrics*, 21, Article 574. <https://doi.org/10.1186/s12877-021-02436-y>
6. Bianchi, C. (2020). *End-to-end health and safety monitoring*. KENZEN. <https://kenzen.com/end-to-end-health-and-safety-monitoring/>
7. Binette, J., & Farago, F. (2021). *2021 home and community preference survey*. AARP Research. <https://doi.org/10.26419/res.00479.001>
8. Bosch-Farré, C., Malagón-Aguilera, M. C., Ballester-Ferrando, D., Bertran-Noguer, C., Bonmatí-Tomàs, A., Gelabert-Vilella, S., & Juvinyà-Canal, D. (2020). Healthy ageing in place: Enablers and barriers. *International Journal of Environmental Research and Public Health*, 17(18), 6451. <https://doi.org/10.3390/ijerph17186451>
9. Caplan, Z. (2023, May 25). *U.S. older population grew from 2010 to 2020 at fastest rate since 1880–1890*. U.S. Census Bureau.

- <https://www.census.gov/library/stories/2023/05/2020-census-united-states-older-population-grew.html>
10. Caruso, M., & Harrington, S. (2024, February 14). *Prevalence of limb loss and limb difference in the United States*. Avalere. <https://amputeecoalition.org>
 11. Centers for Disease Control and Prevention. (2024, May 9). *Facts about falls*. <https://www.cdc.gov/falls/data-research/facts-stats/index.html>
 12. Centers for Disease Control and Prevention. (2024, June 3). *Chronic disease indicators: Older adults*. <https://www.cdc.gov/cdi/indicator-definitions/older-adults.html>
 13. Centers for Disease Control and Prevention. (2024, September 3). *Depression and aging*. <https://www.cdc.gov/healthy-aging/about/depression-aging.html>
 14. Centers for Disease Control and Prevention. (2024, October 4). *About chronic diseases*. <https://www.cdc.gov/chronic-disease/about/index.html>
 15. Centers for Disease Control and Prevention. (2024, October 29). *Suicide data and statistics*. <https://www.cdc.gov/suicide/facts/data.html>
 16. Centers for Disease Control and Prevention. (2024, December 19). *Nursing home care*. <https://www.cdc.gov/nchs/fastats/nursing-home-care.htm>
 17. Choi, D., Choi, H., & Shon, D. (2019). Future changes to smart home based on AAL healthcare services. *Journal of Asian Architecture and Building Engineering*, 18(3), 190–199. <https://doi.org/10.1080/13467581.2019.1617718>
 18. Christopoulou, S. C. (2024). Machine learning for evidence-based telehealth and smart care. *BioMedInformatics*, 4(1), 754–779. <https://doi.org/10.3390/biomedinformatics4010042>
 19. Clancy, A., Simonsen, N., Lind, J., Liveng, A., & Johannessen, A. (2020). The meaning of dignity for older adults. *Nursing Ethics*, 28(6), 878–894. <https://doi.org/10.1177/0969733020928134>
 20. Cleland, J., Hutchinson, C., Williams, P. A. H., Manuel, K., & Laver, K. (2023). Home automation experiences of individuals with disability. *Disability and Rehabilitation: Assistive Technology*, 19(6), 2389–2396. <https://doi.org/10.1080/17483107.2023.2288391>
 21. Cleveland Clinic. (2022, March 9). *Type 1 diabetes*. <https://my.clevelandclinic.org/health/diseases/21500-type-1-diabetes>
 22. Cleveland Clinic. (2023, January 31). *Hypoglycemia*. <https://my.clevelandclinic.org/health/diseases/11647-hypoglycemia-low-blood-sugar>
 23. Cleveland Clinic. (2023, February 17). *Diabetes*. <https://my.clevelandclinic.org/health/diseases/7104-diabetes>
 24. Cleveland Clinic. (2023, November 8). *Type 2 diabetes*. <https://my.clevelandclinic.org/health/diseases/21501-type-2-diabetes>
 25. Corbett, C. F., Combs, E. M., Wright, P. J., Owens, O. L., Stringfellow, I., Nguyen, T., & Van Son, C. R. (2021). Virtual home assistant use by older adults. *International Journal of Environmental Research and Public Health*, 18(3), 1113. <https://doi.org/10.3390/ijerph18031113>

26. Dani, M., Dirksen, A., Taraborrelli, P., Sutton, R., & Lim, P. B. (2021). Orthostatic hypotension in older people. *Clinical Medicine*, 21(3), e275–e282. <https://doi.org/10.7861/clinmed.2020-1044>
27. Dolson, C. M., Harlow, E. R., Phelan, D. M., Gabbett, T. J., & Seshadri, D. R. (2022). Wearable sensors for predicting core body temperature. *Sensors*, 22(19), 7639. <https://doi.org/10.3390/s22197639>
28. Dwivedi, R., Mehrotra, D., & Chandra, S. (2022). Internet of medical things for smart healthcare. *Journal of Oral Biology and Craniofacial Research*, 12(2), 302–318. <https://doi.org/10.1016/j.jobcr.2021.11.010>
29. Facchinetti, G., Petrucci, G., Albanesi, B., De Marinis, M. G., & Piredda, M. (2023). Smart homes for chronic condition management. *International Journal of Environmental Research and Public Health*, 20(2), 1205. <https://doi.org/10.3390/ijerph20021205>
30. Fong, J. H. (2019). Disability incidence and functional decline in older adults. *BMC Geriatrics*, 19(1), 323. <https://doi.org/10.1186/s12877-019-1348-z>
31. Fritz, R. L., & Dermody, G. (2019). AI-driven smart homes for aging in place. *Nursing Outlook*, 67(2), 140–153. <https://doi.org/10.1016/j.outlook.2018.11.004>
32. Gharamohammadi, A., et al. (2025). Smart furniture using radar technology for cardiac monitoring. *Scientific Reports*, 15(1), 1392. <https://doi.org/10.1038/s41598-024-80062-5>
33. Gómez-Ibáñez, R., Bernabeu-Tamayo, M. D., Aguayo-González, M., Watson, C. E., & Escribano, X. (2021). Experiences of above-the-knee amputation. *Clinical Nursing Research*, 30(5), 539–547. <https://doi.org/10.1177/1054773820971873>
34. Hirsch, I. B., & Gaudiani, L. M. (2021). A new look at brittle diabetes. *Journal of Diabetes and Its Complications*, 35(1), 107646. <https://doi.org/10.1016/j.jdiacomp.2020.107646>
35. Hu, M., Han, S., Ghorbany, S., & Zhang, K. (2024). Healthy aging in place with smart technologies. *Encyclopedia*, 4(4), 1918–1932. <https://doi.org/10.3390/encyclopedia4040125>
36. Huang, E. S., et al. (2023). Technology in care of older adults with diabetes. *Diabetes Care*, 46(8), 1455–1463. <https://doi.org/10.2337/dci23-0021>
37. Jiang, S., Yu, T., Di, D., Wang, Y., & Li, W. (2023). Worldwide diabetes burden in older adults. *Diabetes/Metabolism Research and Reviews*. <https://doi.org/10.1002/dmrr.3745>
38. Kario, K. (2021). Home blood pressure monitoring. *American Journal of Hypertension*, 34(8), 783–794. <https://doi.org/10.1093/ajh/hpab017>
39. Kebe, M., et al. (2020). Radar-based vital signs detection. *Sensors*, 20(5), 1454. <https://doi.org/10.3390/s20051454>
40. Khodabakhsh, S. (2021). Life satisfaction in older adults in Asia. *Journal of Happiness Studies*, 23, 1289–1304. <https://doi.org/10.1007/s10902-021-00433-x>
41. Lee, E. J., & Park, S. J. (2020). Smart-home services for biophilic experience. *Sustainability*, 12(20), 8572. <https://doi.org/10.3390/su12208572>
42. Li, W., Yigitcanlar, T., Erol, I., & Liu, A. (2021). Smart home adoption barriers and risks. *Energy Research & Social Science*, 80, 102211. <https://doi.org/10.1016/j.erss.2021.102211>

43. Maswadi, K., Ghani, N. B. A., & Hamid, S. B. (2020). IoT-based smart home monitoring for elderly. *IEEE Access*, 8, 92244–92261. <https://doi.org/10.1109/ACCESS.2020.2992727>
44. Mather, M., & Scommegna, P. (2024, January 9). *Aging in the United States*. Population Reference Bureau. <https://www.prb.org>
45. McCabe, D. (2019). *Katz index of independence in activities of daily living*. NYU Rory Meyers College of Nursing.
46. Mehrjoueresht, P., Hail, R. E., Karsmakers, P., & Schreurs, D. M. M.-P. (2024). Radar-based respiration and heart rate monitoring. *Sensors*, 24(8). <https://doi.org/10.3390/s24082448>
47. Monaghesh, E., & Hajizadeh, A. (2020). Role of telehealth during COVID-19. *BMC Public Health*, 20(1), 1193. <https://doi.org/10.1186/s12889-020-09301-4>
48. Morris-Foster, J. M. (2024). Lifelong learning and successful aging. *Journal of Gerontological Nursing*, 50(8), 11–17. <https://doi.org/10.3928/00989134-20240702-02>
49. Motamed-Jahromi, M., & Kaveh, M. H. (2021). Interventions to improve elderly independence. *Frontiers in Public Health*, 8, 516151. <https://doi.org/10.3389/fpubh.2020.516151>
50. Mun, K., & Kim, J. (2024). Smart home modification program development. *American Journal of Occupational Therapy*, 78(5), 7805205130. <https://doi.org/10.5014/ajot.2024.050651>
51. Myers, M., & Chauvin, B. J. (2020). *Above-the-knee amputations* (PMID: 31335070). National Library of Medicine, National Center for Biotechnology Information. <https://www.ncbi.nlm.nih.gov/books/NBK544350/>
52. Nall, R. (2022, March 31). *Amputation: Causes, statistics, and your most-asked questions*. Healthline. <https://www.healthline.com/health/amputation>
53. National Academies of Sciences, Engineering, and Medicine. (2022). *The national imperative to improve nursing home quality: Honoring our commitment to residents, families, and staff*. National Academies Press. <https://doi.org/10.17226/26526>
54. National Institute on Aging. (2020). *Strategic directions for research, 2020–2025*. <https://www.nia.nih.gov/sites/default/files/2020-05/nia-strategic-directions-2020-2025.pdf>
55. Newman, C., & Dinneen, S. F. (2019). Brittle diabetes revisited: Erratic and difficult-to-control diabetes in an elderly woman with type 1 diabetes. *Diabetic Medicine*, 37(10), 1777–1780. <https://doi.org/10.1111/dme.13972>
56. O'Brien, K., Liggett, A., Ramirez-Zohfeld, V., Sunkara, P., & Lindquist, L. A. (2019). Voice-controlled intelligent personal assistants to support aging in place. *Journal of the American Geriatrics Society*, 68(1), 176–179. <https://doi.org/10.1111/jgs.16217>
57. Obuobi-Donkor, G., Nkire, N., & Agyapong, V. I. O. (2021). Prevalence of major depressive disorder and suicide-related outcomes in the geriatric population: A review. *Behavioral Sciences*, 11(11), 142. <https://doi.org/10.3390/bs11110142>
58. Office of Disease Prevention and Health Promotion. (2024). *Social determinants of health*. <https://odphp.health.gov/healthypeople/priority-areas/social-determinants-health>

59. Oladindrin, O. T., Mesthrige, J. W., Ojo, L. D., Alencastro, J., & Rana, M. (2023). Smart home technologies to facilitate ageing-in-place: Professionals' perceptions. *Sustainability*, 15(8), 6542. <https://doi.org/10.3390/su15086542>
60. Ota, H., Chao, M., Gao, Y., Wu, E., Tai, L.-C., Chen, K., Matsuoka, Y., Iwai, K., Fahad, H. M., Gao, W., Nyein, H. Y. Y., Lin, L., & Javey, A. (2017). 3D-printed earable smart devices for real-time core body temperature monitoring. *ACS Sensors*, 2(7), 990–997. <https://doi.org/10.1021/acssensors.7b00247>
61. Padhan, S., Mohapatra, A., Ramasamy, S. K., & Agrawal, S. (2023). Artificial intelligence and robotics in elderly healthcare. *Cureus*, 15(8), e42905. <https://doi.org/10.7759/cureus.42905>
62. Pratley, R. E., Kanapka, L. G., Rickels, M. R., Ahmann, A., Aleppo, G., Beck, R., ... Miller, K. M. (2020). Effect of continuous glucose monitoring on hypoglycemia in older adults with type 1 diabetes. *JAMA*, 323(23), 2397–2406. <https://doi.org/10.1001/jama.2020.6928>
63. Raghunath, N., Dahmen, J., Brown, K., Cook, D., & Schmitter-Edgecombe, M. (2020). Digital memory notebook applications for mild cognitive impairment. *Disability and Rehabilitation: Assistive Technology*, 15(4), 421–431. <https://doi.org/10.1080/17483107.2019.1587017>
64. Ratnayake, M., Lukas, S., Brathwaite, S., Neave, J., & Henry, H. (2022). Aging in place: Are we prepared? *Delaware Journal of Public Health*, 8(3), 28–31. <https://doi.org/10.32481/djph.2022.08.007>
65. Reynolds, C. F., Jeste, D. V., Sachdev, P. S., & Blazer, D. G. (2022). Mental health care for older adults: Recent advances and new directions in clinical practice and research. *World Psychiatry*, 21(3), 336–363. <https://doi.org/10.1002/wps.20996>
66. Riekert, S. A. (2021). The home healthcare nurse: A concept analysis. *Home Healthcare Now*, 39(4), 194–202. <https://doi.org/10.1097/NHH.0000000000000961>
67. Rohmetra, H., Raghunath, N., Narang, P., Chamola, V., Guizani, M., & Lakkaniga, N. R. (2021). AI-enabled remote monitoring of vital signs for COVID-19: Methods, prospects, and challenges. *Computing*, 105, 783–809. <https://doi.org/10.1007/s00607-021-00937-7>