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Biological Clocks, Low-Cost Biomarkers, and AI for Healthspan Equity

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Abstract

Biological clocks are central regulators of metabolism, immunity, cognition, and psychological well-being. Longevity medicine increasingly leverages sophisticated aging clocks, biomarker panels, and artificial intelligence (AI) analytics to support clients' longevity efforts. These services are largely inaccessible to all but the most affluent populations. This paper qualitatively synthesizes recent research on biological clocks, health inequities, low-cost routine laboratory tests, and AI-enabled decision support to explore how rhythm-aligned, biomarker-driven, holistic wellness guidance can be made accessible to economically marginalized populations lacking consistent access to high end longevity medicine. This research focused on a qualitative meta-synthesis of empirical and conceptual studies published between 2020 and 2025 targeting biological clocks, circadian health disparities, low-cost biomarkers, and AI-supported digital health in underserved communities. Twenty-two peer-reviewed articles met the inclusion criteria and were analyzed using a coding framework. Emergent themes included:

(1) biological clocks provide a cross-cutting framework linking healthspan to daily behaviors, social determinants, and systemic inequities;

(2) circadian disruption and poor sleep health disproportionately affect low-income communities;

(3) standardized, low cost lab tests offer practical proxies for biological aging and healthspan risk;

(4) hair cortisol concentration (HCC) and related biomarkers provide a scalable window into chronic stress load in marginalized settings;

(5) AI-enabled tools can translate routine lab data and symptoms into tailored, culturally grounded guidance aligned with biological clocks; and

(6) structural barriers must be actively addressed to ensure that AI-supported rhythm-informed care reaches marginalized communities.

Biological clocks and routine laboratories together create a "layman's toolkit" that can be delivered at scale. When integrated into community-based health programs using low-cost digital platforms, these tools have the potential to extend healthspan for communities excluded from concierge longevity resources. Future research should evaluate the efficacy of these low-cost tools in a longitudinal study within marginalized societies.

Keywords: healthspan, longevity, biological clock, artificial intelligence, circadian rhythm, biomarker

Biological Clocks, Low-Cost Biomarkers, and AI for Healthspan Equity

Although significant advances in healthcare have been made over the past century, a large portion of the population continues to suffer from shortened healthspan. We refer to healthspan as the quality of life across the span of existence. The disparity formed by socioeconomic class stratification is significant. Lower-income communities experience an earlier onset of cardiometabolic disease, a higher rate of morbidity, and a reduction in functional independence when compared to more affluent groups.[2] Stress, sleep, environmental exposure, and access to preventive care modalities often align along lines of income, race, and geography.

Healthspan Gaps and Economic Marginalization

While at-risk communities lack tools with the efficacy and affordability to bring about changes in healthspan, individuals with affluence have access to longevity modalities of care like epigenetic aging clocks, multi-omic lab panels, and microbiome sequencing.[6,8] Advanced imaging and concierge integrative care are reaping the rewards of advances in holistic care.[13,16] Emergent technologies such as AI-powered biological clocks and deep-aging models, offer greater precision in evaluating biological age, but their deployment typically occurs in a high-end client setting.[1] The lack of access to these developing technologies amplifies the paradoxical nature of the problem: those most likely to experience a compressed healthspan become those least able to access the high-cost tools they need.

Biological Clocks as a Bridge Between Longevity Science and Public Health

Biological clocks, specifically circadian rhythm systems, govern the timing of sleep-wake cycles, metabolic processes, hormonal release, immune responses, and cognitive performance.[6,8] Developments over the last decade in the design of aging clocks, informed by molecular, physiological, and clinical inputs, can predict disease risk and mortality far more accurately than chronology or earlier circadian-physiology-centric models.[13,16] Interestingly, many of the key inputs to these digital tools are at low or no cost.

Data on light exposure, meal timing, sleep regularity, the timing of physical activity, social interactions, work schedules, and neighborhood conditions can be analyzed to generate powerful real-time assessments for clients.[1] Additionally, these inputs are malleable in that the client can collect the information, apply processing tools, identify points of effect, and make changes directly that create positive outcomes. These changes are also, in principle, available at a minimal cost and do not require future technology to be implemented. Biological clocks offer a promising framework for holistic, low-cost, healthspan interventions that are immediately accessible to underserved populations most in need of change.[2]

Routine Lab Tests and AI: Democratizing Healthspan Insights

Aging-clock models are routinely built with data from standard clinical labs and off-the-shelf electronic health records.[1] Systematic and narrative reviews highlight that aging clocks can be constructed from a myriad of sources like epigenetic, proteomic, immune, and microbiome data, as well as basic cardiometabolic labs and clinical markers widely available in the primary care setting.[6,8,13,16]

Communities are already using low-cost, standardized tests such as lipid panels, HbA1c, fasting glucose, liver function tests, hair cortisol, and albumin/creatinine.[18] The challenge in making significant progress is not in finding data sources but in translating this information into actionable, user-friendly, holistic guidance, particularly for people navigating a complex socioeconomic landscape.

AI-driven digital health tools can play a catalytic role. Integrative digital health strategies and AI-driven support systems can improve access and personalization of care, even in low-resource settings.[1] Application of these resources must, however, be used in an environment that encourages trust, accessibility, and bias moderation.

Purpose of the Present Paper

The paper aims to explore how biological clocks built on routine data, standardized low-cost biomarkers, and AI-enhanced tools can be integrated into a holistic, accessible healthspan framework that serves socioeconomically challenged populations. This research uses qualitative meta-synthesis to integrate findings from recent chronobiology, public health, biomarker, and digital health literature, focusing on evidence-based, realistically implementable mechanistic models outside the affluent longevity community.

Literature Review Biological Clocks and Healthspan

Biological clocks, spanning molecular aging to circadian systems, have proven to be powerful predictors of disease burden, functional decline, and mortality.[6,8,13,16] Clocks built from multi- omic and clinical data can more accurately predict chronic disease and mortality than chronological age alone, suggesting a powerful resource for healthspan-focused prevention.[1] In a similar fashion, temporal medicine, when aligned with circadian and biological rhythms, has been shown to have therapeutic potential for attenuating chronic inflammation and age-specific disease.[2]

Clocks based on epigenetic, proteomic, immunologic, and microbiome data require careful interpretation, but exemplify the functionality of biological timing in health trajectories.[6,8,13,16] These new applications of technology drive home a key point: biological clocks are incredibly powerful when they integrate multi-system information, including routine lab results already available in many underserved communities.

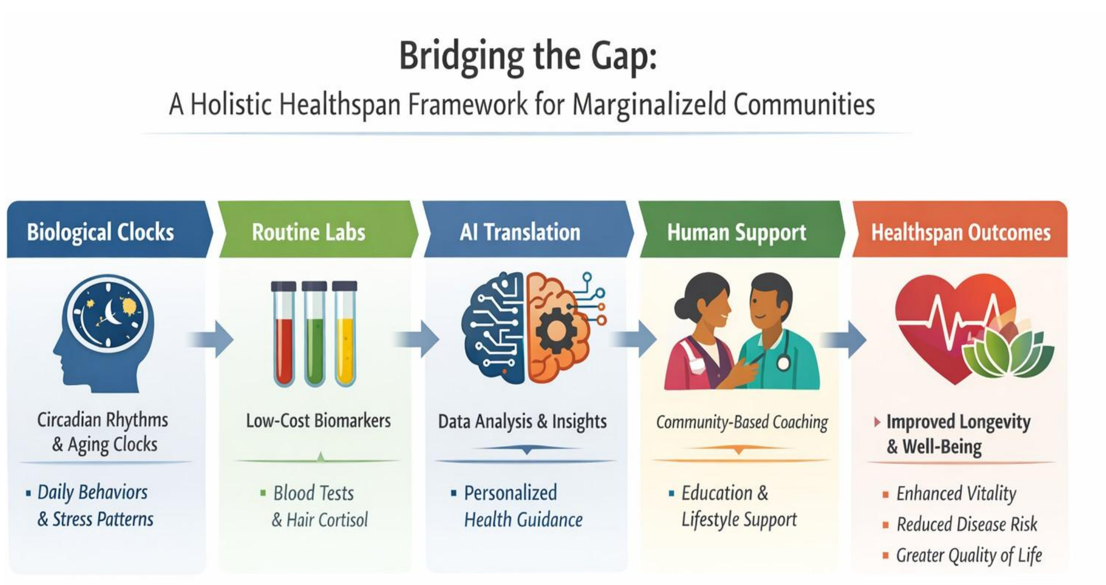

Figure 1 Biological Clock–Informed, Low-Cost, AI-Supported Healthspan Framework for Marginalized Communities

Figure 1 illustrates the proposed conceptual framework integrating biological clocks and low-cost lab work-derived biomarkers, AI-empowered translation, and human-centered support that promotes healthspan outcomes in socioeconomically challenged populations.

Circadian Health and Socioeconomic Disparities

Social and environmental conditions impact circadian health in massive ways.

Multiple studies demonstrate that socioeconomic status, ethnicity, race, and neighborhood conditions significantly predict the duration and quality of sleep, and circadian regularity.[2,6,17]

Disadvantaged groups are more likely to experience short sleep and circadian misalignment due to work demands, shift schedules, noise pollution, light pollution, and neighborhood safety concerns.[2,17] These disparities in sleep and, by extension, circadian rhythm, are strongly linked to cardiometabolic disease, mental health challenges, and the perception of stress. From a holistic perspective, biological clocks are positioned squarely within the social determinants of health rather than just a biological phenomenon.

Low-Cost Blood and Urine Biomarkers as Healthspan Tools

Routine inflammatory and cardiometabolic markers are widely available through community-based clinics, public insurance programs, and low-cost testing services.

Glycemic assays, such as fasting glucose and HbA1c, and lipid panels are foundational for assessing cardiometabolic risk and guiding preventive measures.[11] The triglyceride-glucose (TyG) index, derived from fasting triglycerides and glucose, is emerging as a low-cost biomarker for insulin resistance and future risk of type 2 diabetes and cardiovascular disease. The triglyceride–glucose (TyG) index is typically calculated using fasting triglyceride and fasting glucose values. While exact thresholds vary by population and study design, values above approximately 8.5–8.8 have commonly been associated with increased insulin resistance and cardiometabolic risk in epidemiological studies, whereas lower values generally indicate more favorable metabolic profiles. In this framework, TyG is discussed as a relative risk indicator rather than a diagnostic threshold. Expanded blood panels, including inflammatory markers and cardiac biomarkers, are being investigated to improve the prediction of recurrent cardiovascular events.[7] Because these tools are standardized, inexpensive relative to omics, already recognized and supported by public health programs and commercial insurance, they offer a realistic pathway for AI-assisted healthspan guidance for socioeconomically challenged portions of the population.[10] This is especially true when these tools are combined with temporal patterns that align lab draws with sleep and meal timings.

Hair Cortisol and Other Hair Biomarkers as Chronic Stress Indicators

Also showing promise is the use of hair cortisol concentration (HCC) as a non- invasive biomarker of chronic stress load.[3] In this manuscript, cortisol is discussed specifically as hair cortisol concentration (HCC)**,** which reflects cumulative hypothalamic–pituitary–adrenal (HPA) axis activity over weeks to months rather than acute circulating cortisol levels. This testing reflects the integration of hypothalamic-pituitary-adrenal (HPA) activity over an extended period of observation. HCC has been associated with burnout in health care workers, susceptibility to infection, and behavioral symptom changes in low-income children.[14] Because hair sampling is simple, non-invasive, and inexpensive to process, it is a promising tool for community programs. The use of this tool can objectively quantify toxic stress and lead to advocacy for environmental and policy changes.[12] Other biomarkers, such as hair oxytocin, may further exemplify social-affiliative processes and identify chronic stress in families and their immediate community.

Gut and Microbiome-Related Measures

New research into aging clocks has shown that microbiota composition is informative in evaluating biological aging. Fully sequencing the microbiome may not be feasible in socioeconomically degraded environments, but alternative methods. Like stool-based testing for occult bleeding, simple pathogen panels, and basic diversity indices can inform holistic coaching on fiber intake, inflammatory burden, and diet quality. Combined with circadian-informed nutritional guidance, such as meal timing alignment, this data can support an exploration of the interplay among gut-brain-immune health in a manner accessible to the target audience.

AI, Digital Health, and Equity

Digital and AI-empowered tools are increasingly central to global health strategies.[1] AI-driven diagnostic and decision-support systems can assist clinicians in making more accurate, timely decisions, with the potential to deliver benefits when implemented quickly. Internet access, digital literacy, language, and trust are both barriers and facilitators to the AI's emergent capacity to assist with wellbeing.[5]

The responsible use of AI can increase access to care in underserved communities through tools such as telemedicine, remote monitoring, and decision support.[9] Without deliberate inclusion, however, the advances in AI-facilitated care are likely to continue to remain out of reach of the populace that needs them most. Building these models using off-the-shelf and routine resources, rather than expensive omics, can, in theory, provide the necessary infrastructure to generate healthspan guidance for safety- net populations.[15]

Methods

Study Design

A qualitative meta-synthesis was conducted to integrate findings across diverse chronobiology, biomarker, public health, and digital health studies from 2020-2025.

Following established qualitative meta-synthesis approaches, these findings in this research were interpreted at a conceptual level rather than being aggregated statistically. This approach emphasizes data convergence, divergence, and translational relevance across multiple disciplines. The goal of this literature evaluation was to identify cross- cutting themes relevant to the design of a holistic, rhythm-informed, biomarker- supported, AI-assisted healthspan framework that empowers socioeconomically challenged communities.

Data Sources and Selection

Searches were performed on data from 2020 to 2025 using PubMed, Scopus, Web of Science, and Google Scholar, applying a combination of keywords including circadian, biological clock, sleep disparities, socioeconomic, aging clock, healthspan, routine laboratory tests, TyG index, hair cortisol, digital health, AI decision support, health equity, and underserved. Peer-reviewed empirical or review articles focused on humans and at least one of the following: biological clocks and healthspan, circadian or sleep disparities by SES or race, hair or other biomarkers of chronic stress, low-cost lab biomarkers relevant to long-term health, or AI/digital health applied to underserved communities or health equity.

Qualitative Coding and Analysis

Thematic analysis was conducted in three stages: open coding, axial coding, and selective coding. Open coding extracted text segments to label types of biological clock or rhythm, biomarker type, level of analysis, AI/digital intervention characteristics, and barriers/facilitators for marginalized populations; Axial coding grouped codes into categories, such as temporal misalignment and structural determinants, routine biomarkers as proxies for biological age, hair cortisol as chronic stress gauging, AI decision support bridging or widening access gaps, and community environment rhythms. Selective coding integrated categories into overarching themes, focusing on how biological clocks, off-the-shelf lab tests, and AI could be combined into holistic frameworks. Analytic memos and iterative re-reading were used to support the rigor and coherence of the data.

Results

Theme 1: Biological Clocks Provide a Systems-Level Frame for Healthspan

Within chronobiological and aging clock literature, biological clocks are framed as system-level integrators of risk pathways, including chronic inflammation and immune aging, metabolic dysregulation and insulin resistance, sleep-wake cycle regularity, and cognitive decline. Models like LifeClock demonstrate that routine lab work, combined with demographic and clinical data, can approximate biological age across life stages. For marginalized communities, this implies that healthspan monitoring does not have to rely on costly genomic or imaging tests. This monitoring can be built upon infrastructure that already exists in routine primary care and safety-net settings.

Theme 2: Circadian Disruption Disproportionately Burdens the Economically Marginalized

Research illustrated that socioeconomic status, race, ethnicity, and neighborhood environment significantly predict sleep duration, quality, and circadian regularity. Lower- income workers are more likely to experience shift work, irregular hours, and multiple jobs, all of which disrupt the sleep-wake cycle. Neighborhood noise, light pollution, and anxiety triggered by perceived safety concerns interfere with rest requirements. Sleep and circadian challenges are documented as contributors to cardiometabolic disease, mental health degradation, and heightened perceptions of stress. Temporal misalignment emerges not as a purely individual lifestyle selection but as a condition shaped by structural inequities.

Theme 3: Routine Blood and Urine Tests Are Practical Proxies for Healthspan Risk

Standard cardiometabolic lab tests emerged as practical proxies for healthspan risk and biological aging trajectories. Lipid profiles, HbA1c, and fasting glucose capture cardiometabolic risk effectively and are central to cardiovascular disease and diabetes prevention. The TyG index offers yet another low-cost, computationally simple measure of insulin resistance correlated with the risk of diabetes and negative cardiovascular outcomes. Expanded blood panels that include inflammatory and cardiac biomarkers can further enhance the prediction of recurrent cardiovascular events. Because these tests are standardized, inexpensive compared to omics, and already integrated into many public health systems, they provide a practical and realistic approach to implementing AI-guided healthspan in low-income populations.

Theme 4: Hair Cortisol and Related Biomarkers Provide a Window into Chronic Stress

Hair cortisol concentration consistently tracks chronic stress and is particularly useful in populations facing long-term socioeconomic strain. Elevated hair cortisol has been identified as a potential link to healthcare worker burnout, behavioral difficulties in low-income children, and an increased susceptibility to infection. Hair sampling is particularly well-suited to low-income populations due to its simplicity, non-invasive nature, and low cost. Hair cortisol testing has been explored as an effective measure of chronic stress burden, enabling programs to identify individuals and communities most in need of psychosocial and structural interventions.

Theme 5: AI Translates Biomarkers and Clock Concepts into Personalized Guidance—If Designed for Equity

Decision support consisting of AI is increasingly used to interpret lab data and tailor interventions. AI models can assimilate large data sets and integrate routine labs, demographics, and clinical histories to estimate biological age and risk pathways.

Decision-support systems offer clinicians real-time personalized treatment options and prevention strategies. AI-enabled telehealth platforms are expanding access to expert guidance in underserved communities.

By strategically applying data from biological clocks and off-the-shelf labs, AI can interpret patterns in cardiometabolic labs, hair cortisol, and self-reported sleep data to provide cost-effective, easy-to-understand, tailored recommendations for adjusting meal timings, encouraging consistent sleep patterns, and suggesting stress-reduction practices. These recommendations are all possible at a low entry point, making them accessible without expensive therapeutic interventions. It is still important, however, to ensure that equity is present in these processes and that AI tools address representativeness in data, transparency, language, and cultural adaptation to avoid expanding existing health inequities.

Theme 6: Structural Barriers and Digital Divides Must Be Addressed Intentionally

Even with this promise of equity, barriers still exist. Limited internet access, device availability, the cost of data plans, a lack of trust in institutions and AI tools themselves, and, finally, the bias associated with non-representative AI training data. For a healthspan framework to combine biological clocks, labs, and AI, it must be co- designed with the communities it serves. This system must be transparent and operate in conjunction with human support, such as community health workers or holistic wellness coaches, who can interpret and contextualize the system's outputs. For digital health to be truly equitable, it requires attention to infrastructure, literacy, governance, and an ongoing risk evaluation that considers unintended consequences.

Discussion

The synthesis of biological clocks with low-cost lab tests suggests that these accessible biomarkers and AI tools can create a pragmatic, equitable healthspan toolkit. Biological clocks provide the why, routine blood and urine tests and hair cortisol provide the what, and AI with digital tools provides the how. The outcome of this process is personalized interpretation and guidance that is based on measurable indicators tied to timing and aging biomarkers. It is important to state that this framework does not assert a causal influence but proposes a pragmatic, hypothesis-generated model for behaviorally mediated healthspan extension.

Consider a community member with elevated HbA1c, high triglycerides, a high TyG index, short, irregular sleep patterns due to neighborhood environmental factors, and elevated hair cortisol, indicating chronic stress. Within underserved settings, indices such as TyG may be most useful when tracked longitudinally within individuals rather than interpreted as fixed clinical cutoffs. This person could receive AI-assisted, human- supported guidance grounded in biological clock science. This guidance could include changes such as encouraging sleep improvements through regularity and light exposure to realign the circadian rhythm, adjusting meal timings to align with metabolic clocks, incremental increases in physical activity at consistent times, and stress-reduction strategies tied to cortisol levels, applied over time. All these recommendations are based on low-cost behaviors rather than expensive therapeutics, making them appropriate for individuals with limited resources.

AI can empower users by translating complex biomarker data into actionable, understandable steps, such as simple clock health scores. This lifestyle information would be based on routine labs, simple dashboards that track progress over time, or even SMS- based coaching for those with limited computer access. The use of hair cortisol concentration in this framework is intended as a proxy measure of chronic stress exposure, not as a diagnostic indicator of endocrine pathology.

It is critical, however, to ensure that this empowerment activity is equitable and does not seek to shift blame. There are tangible structural factors that affect a person's ability to act on guidance, including shift work, housing, neighborhood environment, and food insecurity. Targeted use of messaging and human support could account for these constraints and emphasize small, realistic habit shifts while advocating for structural change using aggregated, de-personalized data that speaks to noise abatement, public space safety, and humane work scheduling practices.

AI and lab-based resources are most effective when embedded into a relational ecosystem. Community health workers, holistic wellness guides, and local organizations can help individuals understand their lab and clock-based results, translate these recommendations into culturally relevant practices, facilitate group programs, and provide feedback on what is realistic and respectful within the community setting.

Policy and System-Level Implications

Policymakers and existing health systems could scale this framework by subsidizing key lab tests for low-income, high-risk populations. Integrating biological clocks into clinical and public health settings would facilitate greater access. Providing visible support for open, community-validated AI tools built on diverse datasets, along with investment in digital infrastructure and literacy, would form the foundation of an effective health-focused initiative. Implementation of this framework requires alignment with existing public health infrastructure rather than reliance on novel or proprietary diagnostic platforms.

Limitations and Future Directions

This meta-synthesis brings together a diverse, albeit limited, set of studies, many from higher-income countries and specific subpopulations. Measurable implementation of the proposed integrated lab work and AI-based biological clocks guidance in underserved communities is arguably in its infancy. Few trials exist that test the listed interventions against the stated problem set.

Future research should focus on community-based biological clock programs that combine low-cost labs, hair cortisol, and AI-guided coaching in public clinical settings to evaluate user comprehension, trust, and behavior change. Further research comparing the efficacy of the existing clinical model against a biological clock-based model underpinned by routine labs and socio-economic data would be useful in identifying comparative outcomes in marginalized populations while focusing on healthspan-oriented goals.

It is important to acknowledge that access to even low-cost laboratory tests and biomarker assessments varies widely across socioeconomically marginalized communities. Although markers such as fasting glucose, lipid panels, and HbA1c are commonly available through public insurance programs and safety-net clinics, access to indices such as TyG or hair cortisol concentration may be limited by regional infrastructure, reimbursement policies, laboratory capacity, and workforce constraints. Accordingly, this framework does not assume universal availability of these measures but rather proposes a tiered and context-dependent approach, in which available biomarkers are leveraged pragmatically based on local resources. In settings where laboratory access is constrained, rhythm-aligned behavioral data (e.g., sleep timing, meal timing, perceived stress, and activity regularity) may serve as interim inputs until laboratory capacity becomes available.

This framework is directly relevant to the practice of integrative and complementary medicine. By grounding biological clock science in low-cost biomarkers and rhythm-aligned lifestyle interventions, practitioners can operationalize evidence- based prevention without reliance on high-cost precision medicine. Integrative clinicians may apply circadian-informed guidance on sleep regularity, meal timing, stress modulation, and movement scheduling using routine laboratory data already available in primary care and community clinics.

Importantly, this model supports a non-pharmacologic, systems-oriented approach consistent with complementary medicine principles. Hair cortisol and routine cardiometabolic markers provide objective anchors for assessing chronic stress and metabolic load, while AI-enabled tools can translate these data into culturally appropriate recommendations delivered through human-supported coaching relationships. When embedded in community health programs, this approach aligns integrative medicine with equity-driven public health goals, offering a scalable pathway to extend healthspan in underserved populations.

Implications for Integrative and Complementary Medicine Practice

Biological clocks, low-cost laboratory tests, and AI exist in the realm of affluent, high-tech longevity medicine. This synthesis seeks to reframe these tools to highlight their potential to expand healthspan, using targeted, accessible, and cutting-edge approaches to create impactful change. The power of biological clocks lies in their ability to underpin a framework that links daily lifestyle routines to environmental conditions, stress, and clinical biomarkers, thereby supporting long-term health outcomes. Circadian rhythm and sleep disruptions disproportionately affect lower-income and at-risk communities because of structural determinants, making temporal health an equity issue. Standardized tests, however, can serve as accessible proxies for biological aging and healthspan risk, while hair cortisol and related biomarkers offer a scalable window into chronic stress loading.

Conclusion

AI and digital tools, when designed with equity, transparency, and community co- leadership, can convert biomarker and clock data into user-friendly, culturally grounded guidance that enhances agency instead of generating blame. In a world where the affluent can make the best use of emergent technologies for longevity, biological clocks with low- cost labs represent an entry point grounded in science, scalable, and ethically compelling.

By realigning existing technologies and core laboratory tools, it is possible to support holistic wellness and extend the healthspan for the entire population.

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Conflicts of Interest

The author declares no conflict of interest.

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