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Past, present and future perspectives on the science of aging

As *Nature Aging* celebrates its fifth anniversary, the journal asks some of the researchers who contributed to the journal early on to reflect on the past and the future of aging and age-related disease research, the impact of the field on human health now and in the future, and what challenges need to be addressed to ensure sustained progress.

Is there one advance in aging or age-related disease research from the past 5 to 10 years that changed how you think about the field, and why?

Steve Horvath: If I had to identify the single most paradigm-shifting development, it would be the realization that the epigenome encodes deep, highly conserved information about time, lifespan and developmental pacing across all mammalian species. We learned that the methylome–epigenome contains a universal framework that governs biological time. This realization reframed aging from something purely stochastic into something at least partly programmatic and evolutionarily constrained. The emergence of the pan-mammalian methylation clock — a methylation clock that works across all mammalian species, spanning roughly 100 million years of divergence — still blows my mind. Recent studies by many laboratories show that the epigenome tracks time in a deeply conserved way and together provide one of the strongest arguments to date that aging involves a regulated component linked to developmental processes. Recent insights based on epigenetic clocks also suggest that biological aging is far more malleable than previously assumed, yet remarkably difficult to shift in a durable way. Overall, DNA methylation clocks have effectively opened a new empirical window onto the 'software layer' of mammalian aging biology, and revealed that aging is neither fully stochastic nor fully programmable but a dynamic interaction between conserved developmental programs and environmental inputs.

Vera Gorbunova: For me, this was the invention of methylation clocks. This made quantifying aging possible without waiting for your experimental population to die. This opened way for clinical trials and testing antiaging interventions.

Terrie E. Moffitt: Just a few years ago, human aging research was a field hobbled by the lack of an outcome measure. Most research studied proxies for aging, such as disease morbidity and mortality, but those end points relate only imperfectly to aging itself, and could only practicably be studied in older adults, which rendered findings too late in the life course to inform prevention. The ideal way to study human aging is to observe how people change longitudinally, and to model their pace of aging. But this takes time, and is also not practicable for clinical implementation. The invention of point-in-time methods that capture the longitudinal pace of aging has introduced a new way of measuring aging expeditiously. Using these longitudinal-based measures as outcomes makes it newly possible to carry out randomized clinical trials of geroprotective treatments, to determine whether a treatment can slow aging before people become older adults who have irreversible organ damage. Research shows these measures can be applied to young adults as well as old, and they perform well in a variety of ethnic ancestry groups. Longitudinal-based aging measures capture the essence of the construct of aging, because they quantify an individual's slope of decline in physiological and structural integrity over years of time (and they do this unbiased by the multiple sources of noise that compromise cross-sectional measures of biological age). The new longitudinal measures of aging are breaking the no-outcome-variable barrier, in clinical science and in discovery science.

Daniel W. Belsky: The most important advances in my corner of the field, which is aging biomarker research, are (1) the formation of the Biomarkers of Aging Consortium (BoAC), which is beginning to organize and coordinate efforts across top laboratories around the world towards finally building a subfield that can make real progress; and (2) the advent of studies testing aging biomarkers in randomized clinical trials of interventions that target the biology of aging and aging-related functional decline. In both cases, we see the emergence of standards to hold new biomarkers accountable for generating real progress in the field.

Jin-Tai Yu: The most transformative advance stems from the application of high-throughput proteomics to measure thousands of proteins from biofluid or tissue samples. Whereas genomics provides the blueprint, proteomics delivers a dynamic, functional readout of the body's physiological state. The key revelation is that the proteome is a rich, quantitative signature of biological age that often outperforms other biomarkers in predicting mortality, frailty and the onset of specific age-related diseases. For instance, proteomic clocks provide a more precise quantification in

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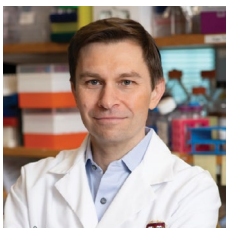
stratifying individuals based on their biological age. Protein signatures can also predict the risk of hundreds diseases years before diagnosis. Proteomics has also reconceptualized aging as a highly heterogeneous, system-wide process. An individual can have a 'young' brain but an 'old' liver. This explains differential disease susceptibility and reframes aging as a 'dialogue' between organs. For instance, an accelerated aging clock in the liver can drive systemic inflammation and metabolic dysfunction, which in turn compromises the blood–brain barrier, fuels neuroinflammation, and accelerates brain aging and cognitive decline. More critically, the proteome provides a direct window into actionable biological pathways. Unlike genetic risk scores, protein levels point directly to dysregulated pathways that can be therapeutically targeted, offer a direct link between biomarkers and potential mechanisms, and dramatically accelerate the translation from basic discovery to clinical intervention.

Tony Wyss-Coray: I think the unbiased 'molecularization' of both measures of aging and rejuvenating interventions. This includes unbiased transcriptomic, proteomic and epigenomic measurement of the processes of aging and observing the results of interventions, including exercise, dietary interventions and others, using the same tools. These studies showed that aging is quantifiable and that interventions can slow and reverse diverse aspects of aging. They started to provide, for the first time, molecular explanations for lifespan and functional measurements. A direct outcome of these advances is the recognition that cells, organs and systems within an organism can have different trajectories of aging and, that individuals within a species — even when genetically identical — can have different biological ages across these organismal units.

Anne Brunet: There have been so many exciting advances in the past 5–10 years! It is hard to pick, but I think advances in high-dimensional technologies, machine learning and artificial intelligence (AI) have really changed the aging field, by allowing quantitative and predictive measurements. For example, 'aging clocks' that predict age or remaining lifespan, first pioneered by Steve Horvath for DNA methylation. Since then, different clocks have been built by many laboratories — for instance, our laboratory and collaborators have developed clocks based on single-cell transcriptomics, spatial transcriptomics and behavior. It has been exciting to see how these clocks can quantify the rate of aging and even forecast future aging trajectories. What is also really cool is that such unbiased approaches can be used to predict, early on, the effect of interventions and to identify new 'longevity' strategies. These unbiased approaches are also opening up entirely new questions about resilience and rejuvenation.



David A. Sinclair: The discovery that DNA methylation changes track chronological age was transformative for me. Beyond providing the first quantitative aging clock, it offered strong support for what we then called the 'RCM (relocalization of chromatic modifiers) hypothesis' — now the information theory of aging. The information theory of aging posited that epigenetic drift is a primary driver of aging and that cells retain a backup copy of youthful epigenetic information. Then in 2016, Juan Carlos Izpisua Belmonte's group demonstrated that cyclic OSKM (OCT4, SOX2, KLF4 and MYC) expression could rejuvenate tissues in progeroid mice, and work led by Y. Lu in my laboratory later showed that partial reprogramming via OSK can reverse aging and restore cell identity safely and robustly. Together with complementary findings from colleagues including Vittorio Sebastiano, Shelley Berger, Vera Gorunova, Andrei Seluanov, Lenny Guarente and Peter Adams, these advances have strengthened the view that the epigenome retains recoverable youthful information and that aging is, in principle, safely reversible.

Juan Carlos Izpisua Belmonte: In my view, one of the most important advances has been recognizing that aging is not just the sum of changes inside individual cells, but a gradual loss of homeostasis and coordination across the whole organism. Even if some cells remain functional, the collective orchestration and coherence of the organ and organism weakens with time. Studies in which old animals are exposed to young blood, through parabiosis or plasma-derived factors, show that aspects of regeneration, metabolism and even cognition can improve. These results change how we think about aging, showing it to be a form of communication between tissues that weakens with time but can still be partially restored. In our work, we have shown that partial reprogramming can reverse mesenchymal drift and help to restore some of this orchestration by adjusting organism-wide signaling and promoting a more youthful systemic environment. Therefore, rejuvenation may not only come from acting on single pathways but also from improving the broader networks that support repair, identity and resilience throughout the organism.

David Furman: The advance that truly changed the way I think about aging is partial cellular reprogramming. When the first studies came out showing that you could briefly turn on a set of reprogramming factors and watch old tissues regain youthful function, without losing their identity, I remember feeling a genuine disbelief followed by possibility. For years, we have thought of aging as inevitable, but partial reprogramming showed that cells carry a kind of 'memory' of youth — a blueprint they can return to if we nudge the system in the right way. Suddenly, aging looked less like an irreversible decline and more like a state the body shifts into when certain regulatory circuits drift off balance. That is a profound shift for both science and medicine.

Matt Kaeberlein: My views on species maximum lifespan and the underlying biology behind it have evolved considerably over the past five years. I have come to appreciate that the mechanisms that determine species maximum lifespan in humans may differ fundamentally from those that govern median lifespan or individual variation.

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The mechanisms of aging we currently understand — perhaps best conceptualized by the hallmarks of aging — may not be the same ones that set the upper boundary for lifespan. Modeling work by P. Fedichev and others is consistent with this idea. I also suspect that our inability as a field to identify large-effect interventions that substantially increase lifespan in mammals may reflect the existence of a biological 'barrier' of sorts. This remains speculative, but understanding whether such a barrier exists may be essential for achieving extreme lifespan extension.

Steve N. Austad: The discovery that a large fraction of pro-longevity interventions, either drugs or genetic alterations, have turned out to have sex-specific effects. No one suspected that would be the case — particularly in mice, in which there is no consistent sex difference in longevity. Understanding these sex differences now strikes me as one of the major goals of the field. If we could make men live as long as women, and women maintain their functional health as well as men, we would be doing a great service to the field.

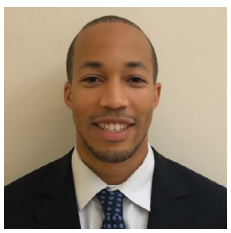
Dudley W. Lamming: I think one of the biggest developments over the past ten years has been the realization that dietary composition can be just as important in regulating aging and age-related disease as the number of calories. My own work has focused very heavily on protein and the branched-chain amino acids, and my laboratory (as well as a number of groups around the globe) have now shown that these dietary components — especially the branched-chain amino acid isoleucine — regulate not only metabolic health but also lifespan in model organisms. Other dietary modifications such as ketogenic diets have also attracted a lot of attention for their ability to promote longevity and preserve cognition in model organisms.

Eric Verdin: The most transformative advance for me has been the realization that immune aging is not just one component of aging but a central orchestrator of the entire process.

Single-cell immune atlases, the biology of clonal hematopoiesis of indeterminate potential, inflammaging signatures and immune aging clocks have revealed that immune dysfunction emerges early and drives decline across multiple systems. Similarly, primary mutation in the immune system can drive senescence in non-immune tissues. This reframes aging as a problem of lost resilience rooted, at least in part, in immune dysregulation. It explains why lifestyle factors — sleep, stress, nutrition, exercise and social connection — have such profound biological effects: they are all potent modulators of immune tone. This shift has unified many previously disconnected findings and reshaped my priorities towards interventions that preserve or restore immune adaptability as a cornerstone of extending human healthspan and lifespan.

Michal Schwartz: I believe that one of the most significant paradigm shifts over the past decade in understanding the relationship between aging and age-related diseases, at least with respect to the brain, is the role of the immune system. Throughout much of the 20th century, the prevailing view held that the brain was completely isolated from the immune system and, consequently, neurological conditions were regarded as brain-autonomous processes. Approximately two decades ago, it was still highly challenging to persuade the scientific community that the brain is not isolated from the immune system but is, in fact, functionally dependent upon it. Currently, the central question is no longer whether the immune system cross-talks with the brain, but how harness this communication to promote brain health and resilience. This conceptual transformation reframes our understanding of the brain, not as an immune-privileged organ entirely secluded from systemic circulation but as one that maintains dynamic bidirectional communication with peripheral immune mechanisms. Therefore, much research in brain aging and neurodegenerative diseases is shifting from a narrow focus on targeting brain pathologies that requires drugs that get access to the brain by overcoming the blood–brain barrier, to a broader approach that considers targeting systemic immunity to boost its ability to support neuroprotection, and repair.

Maxim N. Artyomov: Single-cell RNA sequencing has opened an unprecedented window into the complexity of human tissues, enabling us to begin deciphering how individual cells interact and collectively shape the aging process. What stands out is the remarkable robustness of tissues and organisms during healthy aging. Although aging predisposes to many diseases, physiological aging itself — when not burdened by pathology — appears more as an adaptive process than simple deterioration.



Keenan A. Walker: High-dimensional data (omics) has elucidated the biological heterogeneity that underlies many of age-related conditions, including Alzheimer's disease and physical frailty. This has challenged how the field thinks of the pathophysiology that underlies these conditions, and the treatment options. By continuing to embrace this complexity, understanding and quantifying heterogeneity, and translating this understanding to a personalized approach to disease prevention and interventions, I anticipate the field will have greater success modifying the course of aging and age-related disease.

Nancy Y. Ip: One significant advance that has changed my perspective on the field is the development of blood-based biomarkers. These biomarkers provide valuable insights into the course and nature of human aging, specifically identifying neurodegenerative diseases, their pathologies and the biological pathways involved. With a simple blood draw, we can now detect signals associated with Alzheimer's disease, other neurodegenerative disorders and vascular injury, while also tracking related pathways such as amyloid, tau,

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neuroinflammation and neurodegeneration. As we continue to explore these biomarkers, I anticipate significant progress in identifying new actionable therapeutic targets, enabling more precise patient stratification, and advancing precision medicine approaches for complex age-related conditions such as Alzheimer's disease. Ultimately, this shift will help to tailor interventions to individual needs and drive transformative improvements in both prevention and treatment.

Oskar Hansson: In 2020, it was shown that p-tau217 (tau phosphorylated at residue 217) was an accurate biomarker for both preclinical and clinical Alzheimer's disease. Plasma p-tau217 has already started to revolutionize clinical practice and trials. Now, Alzheimer's disease can be accurately diagnosed in primary care, and we can effectively conduct therapeutic trials in people with Alzheimer's disease who have not yet developed any symptoms.

Linda P. Fried: The aggregate advances in our knowledge over the past 5–10 years (and even greater if taking into account what we have learned in the past 20–30 years) have created the ability to set vision and goals for accomplishing healthy aging or healthy longevity — for all of us. One large category of advances is that we now know that health is malleable at every age, including old age; that prevention and health promotion is both effective and a critically important investment that creates positive health futures at every age of life and into the oldest ages. We have learned that the foundation of healthy longevity is population-based investments in every community in education and public health's health-supporting environments and conditions that enable healthy lifestyles and optimize health while preventing adverse outcomes. Research is needed to advance this understanding for all people of how to effectively prevent poor health while improving health across the life course, and to better understand the assets and capabilities of older age, from advanced thinking and analysis capabilities to wisdom to generative and prosocial goals, and how to build them.

Bruno Vellas: The concept of intrinsic capacity.

Jinkook Lee: One of the most important advances in aging research has been fueled by the recognition that the dynamic aspects of the aging process are driven by multiple interrelated factors; health influences social and economic engagement, and social and economic resources affect the onset of age-related diseases.

Becca R. Levy: One particularly transformative advance for me has been the growing evidence that our beliefs about aging can significantly influence many aspects of our health. For example, in a recent study we found that about half of the older persons who experience mild cognitive impairment recovered to a normal level of cognition and this improvement is significantly more likely to occur if the older persons have assimilated positive age beliefs from their culture. This finding has broadened my thinking about a trajectory of improvement that is possible in later life and has convinced me that age beliefs, which are malleable, can become an important resource for resiliency.

John W. Rowe: In social science and epidemiology, a very important shift has been from the prior almost-exclusive focus on the last stage of life to a much-more-informed life-course perspective, recognizing the critical importance of the accrual of advantage or disadvantage over time. We are increasingly studying not only what older persons are like but also how they became that way, with an emphasis on factors that drive healthy longevity.

Andrew J. Scott: For me, almost a cliché as an economist, it has to be the growing allocation of resources — both financial and academic — to the issue and the sense of a field that is laying down foundations and building on them and making progress. There is a definite shift from framing a problem to understanding mechanisms. Intellectual progress often occurs by discovering the extent of what you do not know, but there is a distinct feeling of knowledge accumulating.

What have we learned about translating geroscience from model organisms to humans, and where do the biggest gaps remain?

Dena B. Dubal: We have learned that many longevity pathways identified in worms, flies and mice are indeed relevant to humans. But as both a physician and scientist, my main conclusion is that we are at the beginning of true translation. One of our biggest gaps is rigor. We need carefully designed, adequately powered, randomized, double-blind, placebo-controlled clinical trials that directly test whether targeting aging biology — or longevity factors themselves — improves outcomes that matter to people. That is true even when interventions are marketed as 'supplements' or 'wellness' products that lack US Food and Drug Administration (FDA) regulations. The promise of our findings as a field is enormous, but we cannot shortcut careful clinical testing without risking harm to people.

VG: I do not think we have translated much as of yet. Human clinical trials are just beginning, now enabled by the invention of multiomics biomarkers of aging. We need more basic research to develop mechanism-based interventions that could be safely translated to humans. Currently, most up-and-coming

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clinical trials are supplements with unclear mechanisms of action.

SNA: We have learned that we are very bad at translating geroscience from model organisms to humans. There is a greater than 90% failure rate if we can extrapolate from findings in age-related diseases. At this point, it is not clear whether the problem is the model species themselves — all short-lived — or the way we use them. Our model species are kept in environments that fail to replicate even the most basic features of their evolved biology. Their environments are unchanging, depauperate in sensory stimulation, spatial complexity and normal microbial experiences, and unchanging food is continuously available. They have no opportunity for physical activity or reproduction. Some of these things (for example, microbial exposure and environmental complexity) we know have major effects on immune function, physiology and neurobiology. We do not know for sure whether making their environments more realistic and diverse would make translation more successful, but that could easily be discovered.

Alex Zhavoronkov: Years of experience in the biopharmaceutical industry convinced me that in the context of drug discovery, animal models with rare exceptions are not representative of human diseases or aging. Only human data can be trusted.

Fabrisia Ambrosio: A persistent gap in translational geroscience has been the limited understanding of the sex-specific mechanisms that drive aging trajectories. Despite implementation of the National Institutes of Health (NIH) 'Sex as a Biological Variable' policy, translational progress remains limited because the most commonly used models fail to capture key signatures of human female aging, including menopause and pregnancy. The result has been the exclusion of key features that dominate late-life physiology in half of the population.

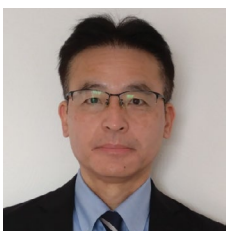
Beyond model considerations, geroscience also tends to rely on static analytical frameworks, even as clinical evidence highlights aging as a dynamic and nonlinear continuum. Evidence suggests that distinct — at times opposing — mechanisms dominate in early-, mid- and late aging. Despite this, most studies compare young versus old models, often under the assumption that conditions can be linearly traced back to antecedent events. Innovative analytical frameworks that model aging as a sequence of dynamic transitions across the lifetime may accelerate the pace of translational geroscience discoveries.

TEM: The move from slowing fundamental processes of aging in model organisms to slowing aging in humans is not as simple as prescribing a pill and watching it work. As compared with aging in model organisms, human aging has many more heterogeneous multifactorial origins and influences, including personality traits, intelligence, social connection, purpose in life, perceived stress, smoking, early-life adverse experiences and psychiatric history. Humans vary widely in such factors, and this variation generates differences between individuals in the pace at which they age. Human-relevant factors such as these have not been studied in geroscience's model organisms. Behavioral science will span the gap between having a gerotherapeutic treatment that looks promising and having one that actually improves the healthspan of the population.

Vadim N. Gladyshev: We learned that even the best interventions yield only marginal lifespan gains in mice, contrasting with the radical lifespan differences observed across mammals, and that the longevity effects seen in laboratory models and those operating across species in nature arise from largely distinct mechanisms. If we aim to meaningfully extend human lifespan, our approach must be both multispecies and multimodal. We currently lack even a single intervention that is proven to extend human lifespan. Targeting damage accumulation (the rise of the deleteriome) remains a promising direction, but substantial gaps persist: we need a deeper understanding of what defines the profound lifespan differences between short-lived and long-lived species, how biological systems both exploit and resist entropy, and, critically, the causal structure that underlies age-related changes.

EV: We've learned that mechanisms translate generally well, but effect sizes do not. Pathways such as mTOR, AMPK, mitochondrial quality control and senescence behave similarly across species. The challenge is that humans are far more heterogeneous than mice — genetically, environmentally and behaviorally. Interventions that extend lifespan dramatically in controlled animal models show modest, variable effects in humans. The biggest gaps remain: (1) the lack of longitudinal human phenomics; (2) no regulatory-accepted biomarkers of aging; (3) the need for multimodal, lifestyle-integrated interventions; and (4) the difficulty in running prevention trials in healthy adults. Closing these gaps requires shifting from organism-first to human-first geroscience, supported by large datasets and real-world biology.

SH: One of the clearest lessons is that although many hallmarks of aging are deeply conserved, the magnitude and durability of intervention effects can differ markedly across species. Epigenetic clock analyses have shown that several interventions with robust lifespan benefits in rodents yield only modest or transient age-reversal signatures in humans. For instance, the epigenetic responses to therapeutic plasma exchange, caloric restriction and rapamycin in humans have been far smaller than what is observed in mice. When I think about where the major gaps still are, three areas stand out. First, we need to establish mechanistic equivalence. Which of the pathways we manipulate in animals actually have the same causal power in humans? Many interventions look powerful in mice but simply do not translate with the same potency. Second, there is the issue of durability and dose. In humans, we often see short-lived changes in epigenetic aging rather than the sustained rejuvenation observed in model organisms. Learning how to produce lasting effects is one of the key translational challenges. Finally, we need greater diversity in our research models and more realistic environments. Broadening the genetic landscape and the exposure will probably be valuable if we want interventions that work robustly in the real world.



Eiji Hara: Genetic studies have revealed evolutionarily conserved mechanisms that regulate aging, such as the insulin–IGF1 signaling pathway, from yeast to

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primates. However, the biggest gaps remain in several critical areas: first, the lack of validated biomarkers for biological age that can be used in human clinical trials; second, the challenge of designing interventions that are both safe and effective over decades rather than the shorter lifespans of model organisms; and third, understanding species-specific regulatory mechanisms that have emerged as organisms evolved into more complex forms, which make direct translation increasingly difficult.

JCIB: Model organisms have taught us that aging is flexible and can be changed by specific interventions. Experiments in worms, flies, mice and other species show how function and lifespan can be extended. But translating these results to humans is not straightforward. These models highlight conserved pathways such as nutrient sensing, stress responses, and mitochondrial and epigenetic programs, but humans have far greater genetic, environmental and physiological diversity. These mechanisms give us a good orientation, but not a complete map. A major gap now is how we measure aging in people. One of the greatest advances is the development of epigenetic clocks elegantly pioneered by S.H. However, we still lack biomarkers that reliably quantify biological aging and predict meaningful clinical outcomes. Although recent progress in multiomic and longitudinal human datasets has been encouraging, we still do not have markers that capture aging dynamics well enough to guide trials. Better ways of measuring resilience, decline and repair, built collaboratively across disciplines and validated in diverse populations, could help to move what we have learned from model organisms to the clinic.

DWB: I think we continue to struggle to map models of aging biology onto human patients. The biomarkers we have that are predictive of healthspan and lifespan come from data-driven machine-learning and AI models that fit omics data (or other big data) to proxy measures of aging biology (years lived, years left to live and rate of physiological decline). These biomarkers are, at best, loosely tied to the hallmarks of aging. The extent to which these biomarkers reflect accumulation of aging hallmarks versus the physiological sequelae of such accumulation remains unknown. In other words, we cannot be certain how much our biomarkers are reflecting the underlying biology of aging versus the downstream effects of that biology on the physiology and function of the organism.

NYI: Model organisms have revealed key mechanisms of aging, such as changes in nutrient sensing, proteostasis, mitochondrial function and cellular senescence. They also show that both lifespan and healthspan can be influenced. In humans, we are validating these mechanisms by connecting genetics, proteomics, metabolomics and blood biomarkers to clinical outcomes. However, significant gaps remain in our understanding of the context and complexity of human aging. Factors such as lifelong exposures, comorbidities, medications and social environments influence aging in ways that model organisms can only partially replicate. To bridge these gaps, we need improved pharmacodynamic assessments in humans, more diverse and truly longitudinal cohorts, and clinical trials that evaluate whether modifying aging pathways enhances healthspan and function, rather than relying solely on surrogate markers.

Parminder Raina: The greatest translational gaps are: heterogeneity in human aging responses, the lack of robust human aging biomarkers, difficulty in designing and executing long-term geroscience trials in humans, and the challenge of predicting clinical outcomes on the basis of animal data. Further, many studies that are published in this space are based on small sample sizes and have very little relevance to real-life aging process. I believe journals have to give more space to innovative analysis from large longitudinal cohorts that are based on populations that are heterogeneous and complex.

The field of aging is very broad, and covers biology, clinical, public health and social sciences. Has your work or thinking been inspired by approaches or findings from separate disciplines?

AJS: For me, the attraction of longevity is exactly this multidisciplinarity. This is not a problem that can be solely addressed in the laboratory or the hospital, or via pension reform. Intellectually, I do find the linkages between the biology of aging and my own discipline striking. The language and models are similar but different, which opens up enormous possibilities of crossovers. Focusing on low-dimensional processes to try and stabilize high-dimensional systems that are vulnerable to external shocks is a common issue for monetary policy as it is the biology of aging, the econometrics of non-stationary trending variables seems relevant to aging, and so on.

VG: Major gaps are remaining between these areas of aging science. More needs to be done to bridge these disciplines. Biologists are focused on slowing down and reversing aging, whereas many clinicians and public health experts are concerned with improving quality of life for older people, with some questioning the ethics of antiaging interventions. We need more forums for these experts to talk to each other. I recently attended a workshop on stress, cancer and aging. I was intrigued by the studies showing how stress and adversity affect cancer outcomes. Patients with identical cancers receiving identical therapies had a higher chance of recurrence if subjected to adversity. It would be interesting to perform a similar analysis of aging and find mechanistic reasons for the differences.

BRL: Yes, my work and thinking have been deeply inspired by approaches and findings from multiple disciplines. As a social psychologist based in a School of Public Health, I collaborate with biologists, statisticians, geneticists, economists, sociologists and clinicians. For instance, my development of the stereotype embodiment theory of aging health, which explores how societal beliefs about aging become internalized and affect older persons' health, draws on methodologies and findings from these diverse fields. I feel privileged to work with talented scientists across these multiple areas to try to improve aging health and well-being.

DF: Absolutely. My work has been shaped as much by fields outside of biology as by biology itself. Systems immunology taught me early on that the immune system does not operate in isolation — it senses the entire lived experience of a person. That insight pushed me towards disciplines that traditionally sit outside of aging biology. From public health and epidemiology, I learned to think about aging as something driven by context: infections, pollution, socioeconomic stress, sleep, diet and social networks. The exposome frame fundamentally changed the way I view chronic inflammation and why individuals age at different rates. From engineering and physics (especially through work on microgravity and organoid models), I gained an appreciation for how mechanical forces and physical environments shape cellular aging in ways we never see in standard biology laboratories.

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And from data science, I learned the power of integrating thousands of variables across time to extract patterns the human mind could never see. My work is a product of many disciplines and aging sits at the intersection of them all — and that is exactly why it is such an exciting field.

MK: Absolutely. My early career focused on the molecular mechanisms of aging in model organisms. Through the Dog Aging Project, I became deeply engaged in translational and clinical (albeit a veterinary clinic) geroscience, which required collaboration across data science, epidemiology, public health and veterinary medicine. Now, as chief executive officer of Optispan, I am building clinical programs and scalable technologies to extend healthspan in people. That work sits at the intersection of geroscience, medicine, AI and data security. It has been striking to see how progress in healthspan medicine depends not only on biological insight but also on engineering, digital infrastructure and ethical implementation.

Which single shared resource (for example, dataset, biobank, model or tool) would most accelerate progress in your field?

Handan Melike Dönertaş: Longitudinal multiomic resources for aging would make the biggest difference. Aging is quite heterogeneous, with individual-specific trajectories, yet almost all datasets (human or model organism) are cross-sectional, which makes it difficult to separate genuine biological change from confounder effects or selection bias. Longitudinal data let us measure the rate and pattern of aging within individuals, detect early deviations from typical trajectories, identify periods of increased vulnerability or stability, and understand how changes in one molecular layer relate to others. In humans, efforts such as the longitudinal collections as part of the UK Biobank and the Human Phenotype Project indicate that it is feasible. In short-lived model organisms, building such resources should already be achievable, but the data remain limited in scope and accessibility.

NYI: Richly phenotyped, longitudinal, multiomics datasets such as the UK Biobank are significant accelerators in our field. The UK Biobank has been instrumental in discovering novel biomarkers for classification and diagnosis, mapping them to underlying mechanisms, and prioritizing therapeutic targets. Equally important, large-scale, harmonized multiomics datasets are ideal for training AI-based models that integrate heterogeneous data for comprehensive risk assessment, prognosis and proactive health management. Expanding repeat sampling and ensuring representation across populations of different ethnicities and ancestries will further strengthen both classical analyses and AI-driven tools, improving robustness and equity in translation.

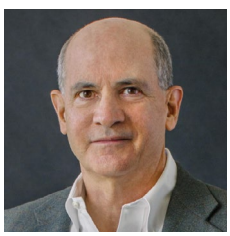
Tohru Minamino: The shared availability of high-resolution, human-derived multiomics data is of paramount importance. Because certain aspects of aging pathology cannot be fully recapitulated in mouse models, the establishment and dissemination of human organoid systems and humanized mouse models will also be essential. Furthermore, integrating these multilayered datasets to build in silico platforms that are capable of predicting therapeutic efficacy in humans would greatly enhance both the efficiency and precision of antiaging drug development.

KAW: The UK Biobank has been an obvious game changer. It has really levelled the playing field in the sense that it has enabled so many talented scientists to generate groundbreaking research, when they may not have otherwise had the resources to do so. There are several other nationwide cohorts providing similar value to the larger research communities (for example, the NIH's All of Us Research Program). Continued investments in these sorts of initiatives will continue to accelerate the field of aging research.

TW-C: In our human-centric studies, data from large biobanks such as UK Biobank or Global Neurodegeneration Proteomics Consortium (GNPC) have been the biggest driver of discovery and there is a tremendous potential to analyze and make available similar datasets. This will require money, political will and buy-in from scientists. In our mouse studies, there is a dire need for establishing large cohorts of animals and profiling them in a similar way to what is being done in humans. Currently, data are extremely scattered or not truly accessible to the community.

AK: A comprehensive multispecies multimodal world model — a computational model that learns the structure, rules and regularities of an environment or world so it can imagine outcomes — of human aging, a so-called life model that is capable of performing multiple tasks that range from age prediction, synthetic data generation, drug discovery and biological reasoning to data analysis, would greatly accelerate progress in my field.

Bérénice A. Benayoun: A major limitation of preclinical aging research has been the models we use — especially the most popular among them: mice. Mouse aging research is overwhelmingly done on inbred C57BL/6 mice (with a few studies, such as the National Institute on Aging Interventions Testing Program, leveraging the heterogenous UM-HET3 paradigm). Although these studies are undoubtedly informative, it is very likely that we are missing a lot of important biology. I believe that a resource of aging mouse colonies from various well-characterized genetic strains (that is, DBA, FVBN, 129Sv, NOD and so on), with the strength of what we know about each of them individually and the differences in how they age (that is, reproductive capacity, ovarian aging, lifespan, metabolic resilience and so on), beyond just C57BL/6 would be an immensely powerful tool to help to decipher gene × environment × system interactions during aging.



Thomas A. Rando: One dataset (or set of datasets) that would accelerate progress in the field would be that that arises from the expanding of studies of one strain of one species under controlled experimental conditions to diverse species, and diverse genetic strains within species, under varied environments that mimic conditions in the wild. We need to understand whether the spectrum of outcomes of interventions that appear to confer

CREDIT: HANDAN MELIKE DONERTAS; TOHRU MINAMINO; BÉRÉNICE A. BENAYOUN; THOMAS A. RANDO

lifespan or healthspan benefits to one strain under the most controlled conditions actually result in loss of fitness in other strains or the same strain under more complex environmental conditions.

How should we balance large, collaborative team science efforts and the focus and agility of individual laboratories to drive research forward? Should there be more big-team science in aging research?

DWB: There should absolutely be more big team science. The field is maturing. There is a need to organize and coordinate efforts. The Biomarkers of Aging Consortium is beginning to do this on the biomarker side. But biomarkers are only one piece of the geroscience agenda. We have seen the power of initiatives such as the Interventions Testing Program for setting standards to define what counts as an effective intervention. We need the same thing for interventions with humans. A geroscience clinical trials network should be a priority for the field.

Jing-Dong J. Han: A balanced, ecosystem-based approach represents the most effective model for modern scientific progress. Large-scale, big-team science is indispensable for generating the vast, standardized datasets and shared platforms that serve as a foundational resource for the community. Conversely, the focused exploration of detailed molecular mechanisms and the development of specialized computational models often thrive in the agile, hypothesis-driven environment of individual small laboratories. This synergistic division of labor leverages the unique strengths of each research structure, and ensures both breadth and depth in scientific discovery.

Guang-Hui Liu: Both modes are essential. Individual laboratories drive innovation through agility and mechanistic depth. At the same time, large consortia, such as the Aging Biomarker Consortium we participate in, provide the scale and diversity needed to tackle complex challenges such as biomarker standardization and large clinical trials. We believe aging research would benefit from more well-organized team science, provided it preserves the creative freedom of individual investigators. Funding structures should support both approaches: bottom-up grants for exploratory science and dedicated programs for pre-competitive consortium projects.

SNA: I like the idea of balance. Big collaborative effects can address certain problems faster and more thoroughly than individual laboratories. I don't know that it needs to be encouraged though, as it seems to me that that type of science is already here and increasing rapidly. The danger of team science though is groupthink within the team. Individual laboratories, I believe, are more likely to make conceptual breakthroughs because they are less susceptible to the groupthink that can overtake an entire field. I think this has been a problem in Alzheimer's disease where the group focus on amyloid to the exclusion of pretty much everything else has held back progress.

TW-C: Yes, although we strongly depend on individual laboratories and free-thinkers to come up with unexpected and unconventional ideas, only big-team science can generate the resources necessary to describe and catalog nature.

BAB: We as a field need to make sure that there is balance for this in aging research; despite the temptation to go all in on large systematic efforts, they cannot provide the granularity to understand system interactions, cell-type-specific responses and so on. Of course, large collaborative team science efforts have transformed what we can do, and the questions we can ask, while also helping to reduce waste and duplications with systematic and standardized frameworks. However, large team efforts will serve aging research best when they are envisioned as supporting the pioneering work that can be made by individual laboratories, focusing on user accessibility and data reusability.

DBD: There should absolutely be more big team science in aging research, supported by resources that prioritize and enable collaborative approaches. At the same time, every investigator, laboratory, institution and university has different strengths – some better suited to individual deep dives and others to team-based efforts. A healthy balance of deep dives, coupled with participation in broader collaborative initiatives, can amplify the reach and impact of aging discoveries. An example of a collaborative approach in aging research is the Simons Collaboration on Plasticity and the Aging Brain (SCPAB), aiming to discover mechanisms of resilience and functional maintenance of the aging brain. This is revolutionary because it brings diverse expertise together – from basic to clinical, cellular to behavioral, genes to circuits, mechanistic to computational, and single cell to organismal – to map the fundamental processes that preserve cognition. No single laboratory could accomplish this alone.

J-TY: The complexity and multifactorial nature of aging make it a quintessential 'big science' problem. However, big science must be deliberately designed to empower, and not overshadow, the creative power of individual investigators. An ideal model is a scaffolded, collaborative network. The large consortia provide the essential macro view and infrastructure; for example, the standardized data, biobanks and shared computational tools. This creates a stable platform from which individual laboratories can launch their focused investigations.

Charlotte E. Teunissen: There are important novel datasets generated by big team efforts that are already available, such as the UK Biobank and the GNPC. These datasets yield relevant insights due to the large number of individuals (population-based aging individuals for the UK Biobank and cases in the GNPC). Yet, there are some limitations, such as the limited curation of formal clinical diagnoses, heterogeneity of sub-cohorts, and large sample size, that may lead to a significant result due to sheer scale – yet the results may be false positive or not meaningful. Therefore, we need to collectively work on rules for study design, such as formulating a hypothesis and providing a biological rationale for that hypothesis. In my view, although these databases are a valuable resource to the field, these should only be used to validate well-grounded hypotheses generated in more curated datasets.

CREDITS: JING-DONG J. HAN; GUANG-HUI LIU; CHARLOTTE TEUNISSEN

Where do you see research on aging and age-related diseases having the biggest impact on clinical care and public health now and in the future?

TW-C: Most diseases unfold in profoundly age-dependent ways. This is true not only for classical age-related conditions but also for infectious diseases and even autosomal dominant genetic disorders. In nearly all cases, disease trajectories are shaped by the age of the individual or by the age-related remodeling of biological pathways relevant to pathogenesis. However, chronological age, and certainly biological age, are largely absent from clinical decision-making. This gap exists in part because we lack widely accepted, quantitative measures of biological age and frameworks to estimate the contribution of aging processes to disease risk and progression. I think that the development of biomarkers of aging, molecular readouts that record the age of cells, tissues, and organs, and their calibration in large, diverse human cohorts will fundamentally transform healthcare. I envision a future in which individuals are routinely monitored from early life onward for deviations in aging trajectories across organ systems. The goal will be proactive intervention: identifying and slowing accelerated aging at the cellular and organ level long before disease manifests. Medicine has already shown the power of this paradigm: routine monitoring of blood pressure and cholesterol has dramatically reduced the burden of hypertension and cardiovascular disease. Aging biology will extend this preventative framework to many more organs, tissues and diseases, and ultimately shift medicine from reactive treatment to true lifelong maintenance of biological function.

SH: One word: prevention.

Jerome N. Feige: Prevention via lifestyle and management of obesity via new incretin-based therapies.

TAR: The greatest impact of research on aging and age-related diseases in the future will be the shift from a focus on treatment to a focus on prevention.

Linda Partridge: There is a general, global swing towards taking a more preventative approach to the impairments of aging. There has also been a swing away from a focus solely on age-related diseases and towards the idea of functional capacity, as defined by the World Health Organization (WHO). Understanding of the biology of aging has much to offer in these contexts, in terms of the use of biomarkers to detect the movement of individuals along a path towards impairment and pathology, and the implementation of tailored interventions. Geoscience also has the potential to provide broader public health interventions, along the lines of statins or drugs that lower blood pressure.

JCIB: As global populations age, bringing biological insights into clinical practice becomes increasingly important. Aging research shows that many chronic diseases share upstream mechanisms, and that these processes act across tissues through systemic communication. Targeting such pathways could help to address several conditions simultaneously, and shift medicine from managing decline to preserving function. In the near term, improvements in biomarkers and biological age measures could allow the earlier detection of risk, more tailored prevention and better monitoring of interventions. Over time, introducing these tools into routine care could help clinicians to act before resilience is lost. The broader opportunity lies in shaping healthcare around systemic biology, measuring resilience across tissues, supporting it when it weakens, and restoring it when possible. If successful, this could help people to remain independent and capable for longer, and enable societies to move from reactive to preventive care.

EH: I see several areas of major impact: first, developing interventions for devastating conditions such as dementia and Alzheimer's disease; second, preventing frailty and maintaining functional independence in older adults, which directly affects quality of life; and third, addressing multimorbidity, which is becoming increasingly common as populations age. In public health, understanding aging mechanisms will enable more effective preventive strategies, and help to compress morbidity into shorter periods at the end of life. Although these advances will take time, I believe they will eventually be realized and transform how we approach healthcare for aging populations.

NYI: The greatest impact will come from our ability to monitor and maintain health throughout the aging process, promoting healthy aging. Recent studies on biomarkers for Alzheimer's disease have enabled earlier detection and clearer risk stratification, which aids in guiding timely interventions and tracking disease activity and treatment response with minimal burden on patients. Over time, integrating biomarker measurements with lifestyle modifications, medications and social support will help to personalize prevention and care, improve quality of life, and reduce the overall burden of age-related diseases across health systems.

JWR: For clinical care, geroscience is nearing the point of developing specific interventions that may be included in clinical trials to target senescence or specific age-related disorders. For public health, to plan and provide for the needs of aging populations, societies must develop a robust capacity to conduct assessments of older individuals' functional status, including specific deficiencies, at the community level. Proven effective tools for such assessments are available from Age Care Technologies (ACT) and the World Health Organization (Integrated Care for Older People (ICOPE)), but have not yet been brought to scale and incorporated as standards of public health practice globally.

Nir Barzilai: First, with the development of biomarkers that reflect not only your biological age but that also change with interventions within a short time. The Advanced Research Projects Agency for Health (ARPA-H) is working on this now. This will open the field, from biology to genetics, and allow the testing of drugs in phase-2-like studies to provide much-needed evidence for the practice of longevity medicine.

JDJH: The biggest impact lies in the paradigm shift from a one-size-fits-all, reactive model to a data-driven, preventive one, and this is being powered by AI. Currently, AI's impact is emerging in early diagnosis and risk assessment. In the future, its greatest contribution will be in creating a framework

CREDITS: JEROME FEIGE; LINDA PARTRIDGE; NIR BARZILAI

for personalized healthspan optimization, in which AI models synthesize an individual's unique data to guide clinical decisions and public health strategies, moving us from treating age-related diseases to proactively managing the aging process itself.

DBD: We have come to understand that biological sex matters in aging. The direct and indirect impacts of this work will ultimately lead to better diagnostics and therapeutics for women's health. For example, when exploring why women live longer in every society that records mortality, we turned to genetic models of sex biology in mice. We discovered that female sex chromosomes contribute to longevity — and that the second X chromosome adds resilience against cognitive decline. Unraveling these X-based mechanisms, grounded in observed human sex differences, may yield new therapeutic targets that amplify resilience conferred by a second X — benefiting both men and women. If we can identify new therapeutic targets rooted in sex biology, the impact will be big.

DF: In the near term, I see two areas transforming clinical practice: (1) inflammation- and immune-based risk prediction tools that quantify chronic inflammation, immune dysregulation and biological aging will allow clinicians to detect risk years before diseases emerge; and (2) personalized interventions that restore resilience rather than just control symptoms. As we understand how the exposome shapes immune aging (through infections, pollutants, stress, sleep and lifestyle), we will design targeted, multimodal interventions that improve whole-body resilience. That includes precision immunomodulators, metabolic therapies, microbiome approaches and lifestyle programs informed by biological aging data rather than population averages. Looking a bit further ahead, organoid models and partial reprogramming will give us safe ways to test rejuvenation strategies and eventually restore function in specific tissues.

VNG: As of now, research on aging has little impact on clinical care or public health, but I expect it to change. In the near term, this will be through: risk stratification, early detection of age-related conditions (for example, using organ-specific clocks), personalized interventions, surgical and oncology fitness, and the amelioration of cardiometabolic decline. In the mid-term, this will be through: menopause and ovarian aging care, neurodegeneration targeting and multimodal primary prevention guided by biomarkers. In the long term, this will be through radically slowing aging with approaches that do not yet exist, but can be inferred from some studies (such as cross-species, replacement, and rejuvenation studies). These approaches will target the aging process itself, not age-related diseases.

DAS: Near-term impact includes the early detection of decline using molecular clocks, risk stratification and targeted interventions. In the longer term, epigenetic reprogramming, senolytics and gene therapies may allow us to restore youthful cellular function, and shift medicine from managing chronic disease to preventing it. Ultimately, targeting aging will be a way to prevent and even cure diseases that current medicinal approaches that address the symptoms (rather than the underlying causes) cannot.

MK: We already know enough to meaningfully extend healthspan in both humans and companion animals. In dogs, for example, we could probably demonstrate a 20–30% increase in healthy lifespan through targeted geroscience interventions — something that would profoundly influence veterinary care, public perception and the lives of millions of people. In humans, we can probably extend average healthspan by 10–15 years today using evidence-based strategies: lifestyle optimization, early disease detection and, perhaps, the proactive use of well-vetted putative geroprotectors. Lifestyle interventions work precisely because they slow biological aging. We should explicitly frame quality nutrition, physical activity, restorative sleep, stress management and social connection as geroscience interventions, because that is what they are.

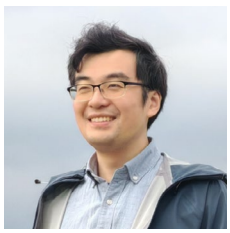
BRL: There is currently a public health crisis around ageism, which Robert Butler defines as "systematic stereotyping and discrimination against people simply because they are old" (R. N. Butler, *The Longevity Revolution: The Benefits and Challenges of Living a Long Life*; PublicAffairs, 2008). Ninety-three per cent of older Americans report experiencing ageism in everyday life. In one study, we found that a 10% reduction in the prevalence of ageism could lead to 1.7 million fewer cases of 8 health conditions (such as cardiovascular disease) among all Americans aged 60 years or older. Thus, uncovering the best ways to fight ageism could substantially improve the health of current and future older persons.

Felipe Sierra: The most critical need is to suppress the snake oil and the large unfounded exaggerations that raise unreasonable expectations. We need to regulate the burgeoning longevity clinics field, so that only bona fide claims based on solid causal science — or at least a considerably large and irrefutable observational body of work — can be sold to the public as 'longevity- or healthspan-enhancing'. There is also an unquestionable need to develop reliable biomarkers, so that we can quantify outcomes before an intervention is approved for public use, including in longevity clinics.

If you could change one funding or regulatory policy to speed up progress, what would it be and why?

VG: I would change the funding policy to allocate grant money to people based on their past accomplishments to save the time wasted on writing and reviewing grants. Grant writing is, for the most part, a pointless exercise as the most impactful discoveries are made when following unexpected results rather than sticking with your proposed aims.

Ashley E. Webb: In general, I would like to see faster and more flexible funding mechanisms that focus on innovation. Although there are some opportunities out there, most of our funding mechanisms still focus on safe, incremental advances. Although the latter approach is important, major advances come from taking a risk on more creative ideas that are actually likely to fail.



Xu Gao: I would prioritize increased support for early-career researchers and smaller, independent research groups. Many funding systems currently favor large-scale, collaborative projects that, although useful in certain contexts, often come at the cost of diversity

CREDITS: FELIPE SIERRA; ASHLEY WEBB; XU GAO

and innovation. By shifting the funding focus to support more early-career scientists and smaller, high-risk projects, we could unlock a wider range of innovative solutions and foster the next wave of transformative discoveries.

HMD: I would change funding policies to recognize data integration, infrastructure development and computational analysis as primary research outputs. Current grant structures often favor generating new data, which makes it difficult for computational biologists to secure support for integrative projects even when the scientific rationale and expected outcome are excellent. We now produce data far faster than we can analyze and understand it, which leaves valuable public datasets underused. Resources such as UK Biobank and GTEx (Genotype-Tissue Expression) demonstrate this clearly: each has supported hundreds of distinct research questions from the same underlying data, which shows how much scientific value can be unlocked without generating new datasets. There should be dedicated funding lines for building computational infrastructure, developing integrative methods and making existing data truly FAIR (findable, accessible, interoperable and reusable).

AB: One funding policy that would speed up progress would be to go beyond the traditional 3–5-year grant model for research. Studying aging is a time-consuming process and many discoveries are abandoned prematurely because the funding stops. Although it may at first seem counterintuitive to lengthen the time of funding to accelerate a process, a longer time frame would boost translation.

DBD: We need a coordinated, global effort to substantially increase funding for aging biology in universities. Adults aged over sixty are the fastest growing population worldwide, and aging is the root driver of most major health problems. Investing heavily in the biology of aging would yield the highest return economically, culturally, societally and individually — accelerating discoveries that could improve human health outcome across nearly every disease area.

MK: I would allocate funding to geroscience research proportional to its impact. Biological aging is the single greatest risk factor for nine of the top ten causes of death in the USA, yet less than one-half of one per cent of the federal biomedical research budget targets aging biology directly. The imbalance is staggering. In my opinion, geroscience research should be funded at a level comparable to the combined support for individual disease-specific research programs.

LP: Many of us are convinced that there will be major advances in prevention of age-related impairments through repurposing of existing drugs for geroprotection. However, these drugs are often both off patent and cheap, so they are of little interest to pharmaceutical companies. Furthermore, the clinical trials needed to assess these drugs for geroprotection will be expensive, because it will be necessary both to establish dose and safety in older people and to assess multiple outcomes, as geroprotection is likely to lower more than one age-related condition. Thus, a major public health opportunity is potentially being missed because of a lack of funding for these trials, which can come only from public sources or charities.

VNG: In funding terms, we should support a large multidisciplinary initiative that focuses on the fundamentals of aging with the idea of achieving radical lifespan changes. Instead of funding diseases, a dedicated NIH institute for geroscience should be created, with streamlined grants and little bureaucracy. This would speed up progress by prioritizing potentially groundbreaking research on aging itself over symptomatic treatments and social and geriatric studies. In regulatory terms, we should aim for the acceptance of validated aging and organ-age biomarkers as surrogate endpoints in adaptive platform trials. This would compress timelines, enable mechanism-anchored approvals, and de-risk prevention. Finally, we should radically decrease the regulatory and bureaucratic burden that scientists face.

SNA: The chief regulatory issue seems to me to be how do we get approval for medications that are mainly preventative? There are some reasonable ideas already out there for some kind of reform (Z. Alexander's THRIVE (Therapeutic Healthspan Research, Innovation, and Validation Enhancement) act, for instance), but I am not convinced that regulatory issues are the big problem. Most reform ideas I hear are more about attracting more investment into the field rather than making it easier to get health-enhancing or health-prolonging interventions approved. My suggestion for funding would be to have a subset of study sections to focus on out-of-the-box ideas. The biggest problem with current funding is that it is so conservative. Reviewers tend to be good at nitpicking and so the least 'nitpickable' applications, which tend to be the most incremental, are most likely to get funded.

JNF: We should create financial incentives for individuals and companies to invest in prevention: for example, via reimbursement lines or tax advantages to solutions that have proven benefits on reducing specific aging symptoms or biomarkers, or the rate of biological aging. We should also create a regulatory framework to enable integrative medical care in which multiple conditions are prevented, or the global aging rate is slowed (for example, with biological age clocks), or managed therapeutically (for example, via aging codes in the International Classification of Disease (ICD)).

GL: I would propose establishing a dedicated pathway for 'healthspan extension interventions'. Current frameworks regulate drugs for specific diseases, but they are not designed for interventions that target shared mechanisms of aging to prevent multiple conditions. A new pathway could recognize validated aging biomarkers as surrogate end points for accelerated approval (similar to practices in oncology), fund long-term trials using composite healthspan outcomes (such as delay in age-related chronic disease onset), and incentivize the development of gerotherapeutics and help to translate promising science into real-world benefits.

NB: A lot of promising substances are nutraceuticals, but we have no idea whether they are good or bad and whether they are safe in combinations. The FDA should have a second nutraceuticals panel that considers clinical studies on nutraceuticals.

CREDIT: GEORGE KUCHEL

George A. Kuchel: I have three suggestions. First, there is currently a regulatory disconnect in the USA regarding compounds considered to be dietary supplements or 'nutraceuticals'. The Dietary Supplement Health and Education Act of 1994 (DSHEA) allows these substances to be sold without FDA pre-approval for safety and effectiveness, and they can be purchased online and in stores without a prescription. At the same time, given the lack of regulatory clarity, the decision on whether an FDA Investigational New Drug application is required is ultimately left to

local institutional review boards, which results in long delays in the research process when extensive Investigational New Drug submissions are necessary, and requires at times the costly and lengthy generation of non-existent safety and pharmacokinetic data. Second, for multisite projects, reviews and approvals of material transfer agreements and data use agreements can lead to considerable delays. However, funders such as the NIH have shown that institutional agreements of acceptance of shared material transfer agreements and data use agreements can be enforced as part of the award process (for example, NIH SenNet Network), which thus greatly accelerates the extent and pace of interinstitutional research collaborations. Third, most funders require that data and new resources generated be shared with investigators after some lapse of time from publication. Nonetheless, the post-award monitoring of compliance with such mandates is generally nonexistent. Although additional burdens on investigators and funding agencies are clearly undesirable, even occasional random spot checks would help to improve the current situation.

MNA: We should simplify access to aged animal models — especially old mice — and rigorously enforce data-sharing policies. Unfortunately, even major journals (including some in the *Nature* family) often fail to ensure that datasets are made publicly available upon request.

DWL: Many of my colleagues believe that aging needs to be an FDA-recognized indication, and that lifting this regulatory bottleneck will speed up progress. For myself, I think a larger issue is a lack of funding support for long-term clinical studies to determine whether some of the generic drugs that extend lifespan in mice can also slow aging and improve healthspan in humans.

EV: We must allow aging itself to be recognized as a clinical indication — not a disease per se, but a risk factor for disease. This is similar to what is being done for hypertension. When we lower blood pressure, we are not 'treating' heart attacks, strokes, kidney failure or dementia directly. We are treating the common cause that gives rise to all of them. Aging works exactly the same way — but on a larger scale. Aging is the ultimate upstream risk factor. It increases the probability of cancer, cardiovascular disease, Alzheimer's disease, diabetes, osteoporosis, immune dysfunction and frailty. Treating the hallmarks of aging is the geroscience equivalent of lowering blood pressure. We are not treating each disease separately; we are slowing the underlying process that drives them all. This is the future of preventive medicine: do for aging what we already know how to do for hypertension. Recognizing aging — or decline in physiological resilience — as an indication would enable preventive trials in healthier populations, attract industry investment and dramatically accelerate translation. No single policy change would have a larger impact on progress in our field.

J-TY: I would promote 'federated learning' frameworks to break down data silos. These frameworks allow the training of shared machine-learning models without pooling all the data in one place, which enables analyses across institutions (for example, hospitals and biobanks) without sharing raw data (thus protecting privacy). Coupled with unified ethical guidelines, this would dramatically accelerate collaboration and discovery in aging and age-related disease research.

There is growing public interest in aging and age-related disease research. What can researchers do to ensure that aging science can be trusted and benefits everyone?

DWB: Don't over promise and under deliver. As more attention and money flow into aging research, the field is losing its hard-earned humility and circumspection to endless hype cycles. Of course, we need to police extravagant claims about fountain-of-youth treatments. But we also need to be more judicious about what we say we know about how aging works and the extent and precision of our measurements of it. The bottom line is: less hype and more transparency would go a long way.

VNG: It is true that we should separate speculation from findings and engage communities on benefits–risks. At the same time, we should avoid black-and-white thinking as criticisms and dismissals may inhibit progress, and hype may couple with true advances. Ultimately, aging science will be trusted and will benefit everyone only when we have real progress. We should think of the aging Manhattan project and earn trust through science.

BAB: Because everyone is aging, and everyone is worried about the effects of aging on themselves or their loved ones, our field is uniquely primed to attract attention from the public. This is why we as aging researchers must always communicate remaining uncertainties to the public. We must resist the temptation to give advice (or feign a certainty we do not have) to the greater public before human studies are conducted. As one example, I am worried about the popularization of direct-to-consumer DNA methylation age products without more guardrails and disclaimers — we know these readouts function well on a population basis but are extremely variable in any given individual. However, they are marketed as foolproof ways to know whether you are aging gracefully. Although caution does not sell as well as gimmicks, it is our responsibility to put caution first to maintain the trust of the public.

Ming Xu: To maintain public trust, transparent communication is essential. We must share not only exciting discoveries but also study limitations, potential risks and alternative interpretations. Crucially, we must emphasize that no intervention should be taken without validation through large-scale, rigorous clinical trials. The premature adoption of unvalidated antiaging therapies by the public poses a significant threat, including direct health risks to individuals as well as substantial damage to the scientific credibility of the aging research field. Furthermore, to ensure broad benefit, clinical trials should actively recruit participants from diverse ethnic, socioeconomic and geographical backgrounds. Finally, a focus on affordable and scalable solutions for these interventions is essential to ensure that the benefits of aging research can be shared by everyone.

MK: Precision and integrity in communication are essential. Scientists must tell the truth, use accurate language and avoid overstatement. We also have a responsibility not to remain silent when others exaggerate or misrepresent data. Credibility is our most valuable asset, and losing public trust would harm the entire field. Equally important, academic scientists should avoid financial and ethical conflicts, particularly selling unproven therapies, supplements or tests. This is especially problematic when deceptive advertising to consumers is involved, as it tarnishes the reputation of the individuals, the institutions and the entire field as a whole.

CREDIT: MING XU

AZ: To ensure that aging research can be trusted and benefits everyone, researchers should focus on delivering tangible clinically proven benefits of antiaging therapies, following the template of GLP1 drugs. Without proven longevity therapeutics, aging research will remain the area of flashy headlines, failed expectations and 'science for the purpose of scientific curiosity'.

JL: Open science is the answer. Making data, programs and codes and the related documents describing those resources available for all interested researchers would be the key. Open science will provide transparency, ensure replicability, enhance rigor and accelerate science.

PR: Researchers can foster public trust and equitable benefits by practicing transparent science, engaging in community dialog, addressing health disparities, and conducting rigorous, replicable research. Standardizing data sharing, publishing negative results and involving diverse populations in studies are also vital. At our institute, we use a design-thinking approach for interacting across disciplines to come up with research questions that are truly interdisciplinary. Throughout this process, we engage with older adults and their families and other stakeholders to ensure transparent science that is of value to the public. We have created centers in hard-to-reach communities to ensure that marginalized communities have an equitable chance of participating in research and its application.

Myriam Gorospe: We need to get outside our comfort zone and share our science with the general public, do outreach presentations in schools, participate in roundtable discussions with lay participants, and so on. More and more research conferences now include conversations with the community. I agree that community audiences are more interested in science than we think, and bringing science to the community helps to build trust!

Evandro F. Fang: I am frequently invited to give comments and opinions in mainstream media in Norway and elsewhere on my views of aging and recent discoveries in this field.

My rules are: (1) tell the truth based on my knowledge; (2) do not exaggerate the interpretation of any big discoveries; (3) tell the audience there is a gap of benefits between bench-top to bedside; and (4) declare my conflict of interests.

FS: Researchers need to learn to get outside of their cocoons and become more outspoken, including being more vocal in debunking dubious claims. I think the field should develop several open forums where such claims get debated transparently in the open, so all involved can more easily grasp the value as well as the caveats of any claim.

What advice would you give to researchers entering the field now?

MG: I have three pieces of advice. One, building studies with omics or big data biology as end point is tempting, but has limited meaning; be sure to go beyond into the biological mechanism, true impact on disease and so on. Two, you should find your niche and pursue something you love even if it is not trendy; you may not have huge competition, but if you do strong work, it will be noticed and will become important. Three (from my personal experience approaching three decades as a mentor), a program built around supporting the new generation of scientists is bound to be successful; if this is a priority, the rest falls into place.

BAB: The time is now! We understand so much more about various aspects of aging biology — spanning neuroscience, immunology, systems biology and so on. We have so many tools that allow the rigorous, unbiased, systematic interrogation of biological systems. Aging research has earned its place in biology as an important field. The field is finally in the position to integrate and expand that knowledge across systems, approaches and models, building on our field's unique, inherent transdisciplinary roots. For newcomers to aging research, my advice is to embrace that uniqueness, to approach aging research without the constraints of any biological subspecialty, and to take that bird's eye view that only newcomers can have. The field welcomes your point of view!

AB: It is an ideal time to enter the field! There are so many new exciting questions, uncharted areas and novel frontiers for fundamental discoveries. For those interested in translation, there are now also many terrific opportunities to translate with many different types of aging companies (for example, Calico, BioAge, Altos, Retrobio and so on) and the possibility of building your own start-up company. My advice would be to join the field, bring energy, test new ideas and have fun!

GAK: Despite the considerable challenges facing trainees and faculty members at early stages of their careers, there has never been a more exciting time to work in the field of aging. Additionally, by focusing on outcomes such as function, independence and quality of life that span varied organs and disease states, few other fields offer such remarkable opportunities for transformative progress in human health at both the individual and societal levels. With all of these considerations in mind, given an opportunity to restart my career, I would once again focus on aging in a heartbeat. In terms of specific advice, I would recommend starting by taking the time to identify one's passions and the types of research that one is attracted to and aligned with. Although no one can be an expert in everything, the future belongs to those who are willing and able to cross traditional conceptual and disciplinary boundaries and silos. First, you should identify a broader question that you are genuinely passionate about, and then select a type of research (basic, human participant, population science and so on) that appeals most to you. Most importantly, you should identify a mentor and a program that will not only provide you with the strongest possible training in your core area of expertise but also encourage and appreciate the importance of getting you out of your comfort zone, and ultimately allow you to develop collaborations across silos, disciplines and experimental approaches.

JCIB: You should remain curious and not feel restricted by existing ideas. Some of the biggest advances in the field have come from challenging what we once thought was fixed. It also helps to build a broad foundation across genetics, epigenetics, metabolism, stem cell biology, computation, immunology and clinical medicine. Aging touches all of these areas, and working across disciplines and with colleagues who bring different skills is essential. Those who navigate these layers with creativity, humility and perseverance, and who collaborate generously, will be best positioned to make lasting contributions. Most importantly, you should remember why we do this work: to

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improve the quality of human lives. Keeping that purpose in mind helps to guide decisions and sustain motivation.

JNF: You should bridge disciplines, embrace new data integration technologies and pick a topic where you are passionate and want to make a difference.

VNG: You can prepare yourself by studying biology, physics and computer science — learn statistics and causal inference, think systematically, focus on aging's essence, develop interdisciplinary skills, pursue bold questions, and collaborate while maintaining curiosity.

HMD: My advice is for computational biologists entering the field is that understanding biology is essential. Running standard pipelines with default parameters is not enough. Although rule-based or AI-driven tools continue to advance and automate routine analyses, impact comes from understanding the theoretical assumptions behind analytical methods and how they apply in specific biological contexts. Aging differs from many diseases with its subtle, systemic and noisy signals. To contribute meaningfully, we need enough knowledge across domains to ask the right questions and know when the assumptions do not hold. The field needs people who can bridge these domains.

J-TY: My foremost advice for researchers entering the field is to intentionally cultivate a deeply interdisciplinary mindset. The era of the pure specialist is fading; the future belongs to those who can act as bridges between traditionally separate domains. Foundational knowledge in molecular biology remains crucial, but it must now be complemented by robust interdisciplinary skills. First, you must embrace computational fluency; second, ground the research in the principles of systems biology; and third, develop literacy in clinical trial design and translational medicine.

NYI: I encourage new researchers to use human data whenever possible and to effectively combine bioinformatics data analysis and wet-laboratory experimental validation. Using multiomics cohorts can help to generate and prioritize hypotheses, while applying careful statistical and causal methods is essential for validating findings with targeted assays and wet-laboratory models to determine mechanisms. New researchers should also become proficient in coding and study design, collaborate closely with clinicians, and plan for external replication and scalability from the outset. Balancing these activities enhances the reliability of findings and increases their potential impact in practice.

JDJH: My first advice would be to embrace AI and computational thinking not just as tools, but as foundational components of your scientific literacy. However, technical skill alone is insufficient. Therefore, my second piece of advice is to cultivate a deep, collaborative partnership with domain expertise. The most successful researchers will be those who can bridge these two worlds, wielding AI with the discernment of a biologist to deconvolve the exquisite complexity of aging.

EV: You should develop a deep grounding in biology, but embrace interdisciplinarity, and learn computation and statistics — they are essential, not optional. It is best to avoid chasing 'miracle' molecules; focus on pathways, networks and resilience. You should seek mentors who balance rigor with creativity, and be willing to tackle difficult, foundational problems. And you should always remember that aging is biological, psychological, social and environmental. The most impactful scientists will bridge these dimensions to build a comprehensive understanding of human aging.

MNA: You should collaborate widely: reach out, share ideas and connect with others in the field — progress in aging research thrives on community and exchange.

AEW: I have always found the aging field to be welcoming to young scientists and established investigators entering the field for the first time, and I think this is a great time to get involved. There are so many conferences to choose from now and most of them are small enough that it is easy to network and get a sense of the field. Some conferences also include a premeeting event for trainees that includes an opportunity to present their work and meet faculty members one-on-one. These events are particularly valuable for career development and establishing collaborations in the field.

FA: The best advice I can offer is to seek out and interact with people who think differently from you. It can be easy to get swept up in groupthink, but innovation often demands approaching a problem from an orthogonal perspective.

TW-C: I recommend you be passionate, creative and bold: enjoy the privilege of doing what you are passionate about and being paid by the public.

VG: We expect groundbreaking advances to happen in aging science. This is a great field to be in as it will affect the future of human society and help to avert the crisis caused by declining birth rates around the globe. My advice is to develop your unique approaches, not to follow in anyone footsteps and try bold things.

AZ: You should focus on the areas that can significantly extend maximum lifespan and maximum productive lifespan in humans: don't go after projects with fewer than 3 years in potential maximum productive life extension. This field needs new disruptive ideas, not just reinforcement of diet, exercise, sleep, diagnostics or 'do what your mother told you' principles.

JL: My advice is to be bold, and be open-minded. Science is so much fun, so enjoy the ride, but please work on an important topic to have impact.

AJS: I offer congratulations on choosing a high-risk and high-return area: few things are as important or intellectual exciting but be aware that intellectual progress rarely follows a straight line — buckle up.

Where do you see your field heading in the next 5 to 10 years?

JCIB: In the next decade, I expect aging research to move from describing decline to restoring function. High-resolution human datasets, from single-cell and spatial maps to longitudinal studies, will provide a clearer picture of how aging progresses across tissues. At the same time, systemic biology will become even more important, with interorgan communication and circulating signals serving as key therapeutic entry points. Clinically, biological age measures will help to personalize prevention and allow earlier intervention. In the long term, I am hopeful that these developments will reshape medicine, and shift the focus from managing late-stage pathology to preserving the biological resilience that enables all of us to remain active and fully engaged in our families, communities and aspirations throughout life.

SH: Over the next 10 years, I expect the field to shift decisively from measuring aging to modulating it in humans. I hope that epigenetic

clocks will continue to mature into tools for evaluating interventions in individuals and even at population scale. My hope is that the aging field will identify safe, well-tolerated interventions that are capable of rejuvenating multiple human organ systems. Some of the early signals we are seeing from GLP1-based therapies are encouraging but they are just the beginning. As multiomics datasets, AI models and causal biomarkers converge, I think we will move to rational mechanism-guided rejuvenation strategies.

BAB: In the next decade, I think the future of our field will be precision geroscience — understanding what shapes aging trajectories and which levers can be potentially acted upon to promote long-term health, not only based on private unique genetic variation but also other important factors that we are just beginning to appreciate, such as biological sex, environmental constraints (for example, urbanization and pollution), social drivers (for example, interpersonal interactions or pet ownership) and life history (for example, pregnancy and lactation, and parenthood). Aging is an integrative process at the intersection of many factors, some of which are mutable and some immutable. The future of our field is in understanding how these factors shape individual aging trajectories, which will provide us with unique handles to personalize our approaches to mitigate the deleterious effects of aging on health.

DWL: I think personalized medicine is going to be recognized as critically important in the response to dietary and other geroprotective interventions. We as a field are now seeing that in mice that different dietary interventions vary dramatically in their efficacy based on the genetic background of the strain — and it seems likely that diet–genotype and drug–genotype interactions with respect to healthy aging will also be observed in humans.

SNA: I see a takeover by massive omics. I am not suggesting this is a bad thing. It will certainly lead to a personalization of health and medical treatments, but I don't think it will lead to the kind of breakthrough that something like antibiotics represented. I think there will be more interventions on the market over that time (mostly supplements) — some might even be effective, although I doubt they will outdo what the best lifestyle choices do now. Real breakthroughs, if they come, will be further out than 5–10 years.

TM: Over the next 5–10 years, I envision aging research evolving into an era of close integration between basic and clinical sciences, much like what has been achieved in hypertension, diabetes and cancer research. As our understanding of the molecular mechanisms that regulate aging deepens, we will see the identification of diverse therapeutic targets and an acceleration in the development of drugs, vaccines and other interventional strategies. Furthermore, advances in genomic and epigenomic technologies will enable personalized approaches tailored to individual aging profiles, and ultimately lead to precision gerotherapeutics.

GL: The coming decade will probably see a shift towards precision geroscience. Multidimensional aging clocks — under development by us and other groups — may become clinically useful tools for quantifying biological age and intervention effects. We anticipate early human trials targeting newly recognized aging drivers, and advances in gene and cell-based regenerative strategies. Critically, the field is moving towards a unified medical paradigm: targeting the root causes of aging to prevent multiple chronic conditions together, rather than individually. Coupled with AI and multiomics integration, this approach could establish a new model of preventive, personalized medicine for healthier longevity.

VNG: I expect to see organ- and systems-resolved aging maps and clinically qualified aging biomarkers; routine real-time biological age monitoring (omics, digital, wearables and imaging); embryo-inspired rejuvenation cues; advances in replacement; insights from long-lived species on complex interventions that slow down aging; and advances in the theoretical understanding of aging. But we should keep in mind that the solution to aging may come not from the aging field.

VG: I expect the first antiaging interventions to be approved and introduced to clinical practice. I see aging biomarkers to become a routine part of a health check-up linked to individualized recommendations on improving healthspan. I also expect the development of safe interventions focused on restoring a more youthful epigenome, and preventative strategies to enhance genome stability and improve DNA repair to become available.

DAS: I expect the emergence of interventions that treat common diseases by resetting cellular age and allowing the body to heal itself. This will include OSK-mediated epigenetic reprogramming, due to be tested in humans in 2026, followed by epigenetic editing, small-molecule reprogramming drugs and AI-guided therapies. Within 10 years, I foresee whole-body rejuvenation.

GAK: I firmly believe that the future of geroscience, and also its most important impact, will be in the prevention of multiple chronic conditions, which are among the most prevalent and typical features of aging in humans. This applies equally to younger individuals without any apparent chronic diseases who may feel invulnerable, and also to older adults with existing chronic diseases who may benefit from preventing the emergence of the next chronic disease, together with the attendant frailty and loss of function. At the same time, despite important and much-needed advances in how clinical care for multiple chronic conditions is being coordinated and delivered at this time, in the longer term gerotherapeutics (whether they involve medications, lifestyle and/or behavioral interventions) represent the most promising avenue for intervening in the pathways that lead to multiple chronic conditions, frailty, disability and lost quality of life.

BV: We will validate biological age biomarkers and will do more and more randomized controlled trials, with some entering phase 3.

JWR: First, there will be a dramatic increase in the number of clinical trials focused on senescence and age-related disorders with interventions arising from geroscience. Second, we are lagging behind in care of older persons and geriatric medicine continues to suffer severe workforce inadequacies, especially for those with low or middle income. Societies must recognize the need and develop incentives, including financial, to bolster all facets of the eldercare workforce including public health, acute care and long-term care. Third, we have largely viewed aging as an accumulation of deficits and have systematically neglected the valuable capabilities that older people bring to society. To successfully manage the demographic transition, we must develop programs and policies that unlock the remarkable social capital inherent in the rapidly growing older population. Fourth, evidence is accumulating that although compression of morbidity may be ongoing in high socioeconomic status groups, it has stalled or even reversed in lower socioeconomic status groups. These adverse trends, if unabated, portend a highly disabled

older adult population. This area requires urgent focus.

OH: In the space of neurodegenerative diseases, I think we are now moving into the therapeutic era, and I hope that the research community will develop several effective and safe interventions for these devastating brain diseases. Personally, I have especially high hopes for different genetic medicine approaches.

MS: I foresee more approved immunotherapies for Alzheimer's disease and other forms of dementia.

AB: The field is moving forward very rapidly, and it is amazing to be part of it! I think there will be several translational breakthroughs in the next 5 to 10 years, notably for devastating age-related diseases such as Alzheimer's disease. Research-wise, it will be very cool to see what happens because so much more is feasible at the organismal level, and it will be an era of quantitative physiology that can be done at scale. We will better know how the untangle causation and compensation, and even leverage compensatory mechanisms. And I think it will be exciting to study more extreme aspects of the longevity and aging field, such as 'suspended animation' and death.

MX: In the next 5 to 10 years, I expect that the field of aging research will make incredible progress in these three directions. (1) I expect to see a significant rise in large-scale, human clinical trials for geroscience interventions that test various senolytics, metformin, rapamycin analogs and many others, These trials will rigorously assess the safety and efficacy of these interventions, with the primary goal of delaying multimorbidity and extending human healthspan. (2) Single-cell and spatial omics technologies will allow us to reveal the cellular and tissue-specific heterogeneity of aging. We will create detailed atlases that show how different cell types age within various organs, and identify novel driver populations for age-related dysfunction. These insights will accelerate the development of a new generation of precise biomarkers that can predict biological age and specific aging vulnerabilities.(3) AI will become an indispensable tool for aging research. AI and machine-learning models will be used to understand the complexity of multiomics data, identify novel aging targets and design personalized therapies. Furthermore, AI will create various predictive models that estimate an individual's rate of aging and project future health risks based on their unique biomarker profile.

EH: Cellular senescence research is currently attracting considerable attention, with growing evidence that senescent cells are deeply involved in aging and various age-related diseases. Many studies suggest that targeting senescent cells could help to prevent or treat age-related conditions. Over the next 5–10 years, I expect we will gain a clearer understanding of several critical questions: which types of senescent cells drive specific pathologies, what are the optimal strategies for selective elimination versus functional modulation of these cells, and what are the potential risks of senolytic interventions. This clarification will enable more targeted and effective therapeutic approaches, and move the field from broad concepts to precision interventions.

JDJH: I envision the next decade as the era when aging research becomes a predictive science. Big data will provide the 'language' of aging — a comprehensive, high-resolution dictionary of biological changes. AI models will be the 'translator', enabling us to read this language to forecast health trajectories, identify vulnerabilities and design personalized interventions long before clinical symptoms appear. The goal will be to move from treating age-related diseases to preemptively managing the aging process itself.

JNF: I foresee high data abundance with AI-driven hypotheses for experiments, clinical trials and epidemiology, in which the ability to extract high-quality data will be a competitive advantage. I also foresee therapies for multimorbidity in the drug space and prevention pulled by general public demand, where geroscience moves from geriatric care to mid-life health optimization via lifestyle.

FS: As with all other areas of human activity, the field will be dominated by AI and other computer-based approaches to translate the biology of aging into interventions. In addition, I believe the field will succeed within the next 5 years at identifying predictive and clinically useful biomarkers that will take us into a more quantitative stage of research. I fear that, combined, AI and biomarkers will 'suck up the oxygen' from more basic mechanistic research, and this in turn will lead to progressively diminishing returns from AI and biomarkers. I also see an opportunity to take advantage of the growing popularity of the field, to engage more robustly not only the general public but also politicians and decision-makers — hopefully leading to significantly increased resources and funding.

MK: I am optimistic that the importance of geroscience will continue to gain recognition, and lead to greater investment from both public and private sectors. I expect substantial engagement from major pharmaceutical companies and anticipate the first FDA approval for a drug that slows aging, probably in companion animals. That milestone would mark a turning point for translational geroscience. Clinically, the landscape will remain frothy for a while. Some longevity clinics already practice evidence-based medicine, whereas others promote unproven or even unsafe interventions. Over time, I expect consolidation around data-driven, ethical standards. AI will also have a central role, and help to reduce disparities and democratize access to healthspan medicine. The long-term opportunity is to bring personalized, proactive health optimization to everyone — not only those who can afford elite care.

A Supplementary Information file containing all the answers received by the journal, unedited, is available.

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Competing interests

J.C.I.B. is an employee of Altos Labs. D.W.B. is an inventor of DunedinPACE, which is licensed to TruDiagnostic, from which he receives royalties. He serves on scientific advisory boards for Hundred Health, WNDRHLTH, Hooke Clinic and X-Prize for Healthspan. D.B.D. reports an issued patent for methods to improve cognition; has consulted for Unity Biotechnology and S.V. Health; co-founded Jocasta Neurosciences to study klotho; and has received research

funding from the National Institutes of Health, the Simons Foundation, the American Federation for Aging Research, the Glenn Medical Foundation, Unity Biotechnology and philanthropic sources. E.F.F. is a co-owner of Fang-S Consultation AS (organization number 931 410 717) and NO-Age AS (organization number 933 219 127); he has a materials transfer agreement (MTA) with LMITO Therapeutics Inc (South Korea), a cooperative research and development agreement with ChromaDex (USA), a commercialization agreement with Molecule AG/VITADAO, an MTA with GeneHarbor (Hong Kong) Biotechnologies Limited and a data license option agreement with Hong Kong Longevity Science Laboratory (Hong Kong); he is a consultant to NYO3 (Norway), AgeLab (Vitality Nordic AS, Norway) and Hong Kong Longevity Science Laboratory (Hong Kong). J.N.F. is an employee of Nestlé Research, part of Société des Produits Nestlé SA. V.G. is a member of the scientific advisory boards for DoNotAge, Elysium, GenFlow Bio and WndrHlth. O.H. is an employee of Lund University and Lilly. S.H. is a founder and paid consultant of the non-profit Epigenetic Clock Development Foundation that licenses the following patents. The Regents of the University of California are the sole owner of patents and patent applications directed at epigenetic biomarkers for which S.H. is a named inventor. S.H. is a principal investigator at the Altos Labs, Cambridge Institute of Science, a biomedical company that works on rejuvenation. M.K. is co-founder and CEO of Optispan, Inc. and co-founder of Ora Biomedical, Inc. He is employed by Optispan and has equity in both companies. D.W.L. has received funding from, and is a scientific advisory board member of, Aeovian Pharmaceuticals, which seeks to develop selective mTOR inhibitors for the treatment of various diseases. T.E.M. is an inventor of DunedinPACE, licensed by Duke University and the University of Otago for commercial uses. The DunedinPACE algorithm is open-access for research uses. D.A.S. is a co-founder, advisor to, board member of, investor in and/or inventor on patents licensed to Life Biosciences, EdenRoc Sciences/MetroBiotech, InsideTracker, Caudalie, Galilei Biosciences and Paradigm 88. Additional information on D.A.S.'s affiliations can be found at https://sinclair.hms.harvard.edu/david-sinclairs-affiliations. C.E.T. has research contracts with Acumen, ADx Neurosciences, AC-Immune, Alamar, Aribio, Axon Neurosciences, Beckman-Coulter, BioConnect, Bioorchestra, Brainstorm Therapeutics, C2N Diagnostics, Celgene, Cognition Therapeutics, EIP Pharma, Eisai, Eli Lilly, Fujirebio, Instant Nano Biosensors, Merck, Muna, Nitrase Therapeutics, Novo Nordisk, Olink, PeopleBio, Quanterix, Roche, Sysmex, Toyama, Vaccinex and Vivoryon. She is editor in chief of *Alzheimer Research and Therapy*, and serves on editorial boards of *Molecular Neurodegeneration*, *Alzheimer's & Dementia*, *Neurology: Neuroimmunology & Neuroinflammation* and *Medidact Neurologie*/Springer, and is committee member to define guidelines for cognitive disturbances and one for acute neurology in the Netherlands. She has consultancy or speaker contracts for Aribio, Biogen, Beckman-Coulter, Cognition Therapeutics, Danaher, Eisai, Eli Lilly, Janssen, Merck, Neurogen Biomarking, Nordic Biosciences, Novo Nordisk, Novartis, Olink, Quanterix, Roche, Sanofi and Veravas. B.V. is founding president of the IHU HealthAge (Research National Agency, France 2030) Toulouse University Hospital and an investigator in clinical trials sponsored by several industry partner. He has served in the past 3 years as a scientific advisory board member for Biogen, Alzheon, Novo Nordisk, Lilly, Eisai, Roche and Johnson & Johnson without personal compensation. K.A.W. is an associate editor for *Alzheimer's & Dementia: The Journal of the Alzheimer's Association* and *Alzheimer's & Dementia: Translational Research and Clinical Interventions*, and is on the editorial board of *Annals of Clinical and Translational Neurology*. K.A.W. is on the board of directors of the National Academy of Neuropsychology. K.A.W. has given unpaid presentations and seminars on behalf of SomaLogic. A.E.W. is a scientific co-founder of Bolden Therapeutics. M.X. has a financial interest related to senolytics. Patents on senolytic drugs (including PCT/US2016/041646, filed at the US Patent Office) are held by the Mayo Clinic. A.Z. is the founder, the CEO and a shareholder of Insilico Medicine, a global AI-powered longevity biotechnology company. He is also a shareholder in Haut.AI, an AI skincare company, and shareholder in Regent Pacific (0575.hk), the owner of Deep Longevity, a company he co-founded; and advisor to LongeVC, a longevity-focused venture fund. All other authors declare no competing interests.

Additional information

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