Health & Technology

A New Map of Life

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Introduction:

Building a sustainable healthcare system to promote healthy longevity

Accessible and affordable healthcare is a cornerstone element in promoting longevity and quality of life. From prenatal visits through end-of-life decisions, healthcare affects literally every life stage. In the U.S., the high cost of healthcare has become a major barrier, impacting individuals and healthcare systems alike. Despite the highest per capita spending on healthcare worldwide, the U.S. appreciates poorer quality health as compared to peer nations(National Research Council (US) & Institute of Medicine (US), 2013). Healthcare costs only continue to grow(Sisko et al., 2019), diminishing opportunities for growth in other economic sectors, and redirecting resources from other national priorities. Extending healthy life has been demonstrated as a cost beneficial means to improve society.(Goldman et al., 2013; Nikolich-Žugich et al., 2016) Further, the wealthiest 1% of Americans are expected to achieve lifespans 10-14 years longer than their poorer counterparts,(Chetty et al., 2016) highlighting the opportunity gap present in our nation to achieve healthy longevity across our entire population. As U.S. life expectancy lengthens, our healthcare system must be reimagined to sustainably provide high-value, cost-effective care for the duration of our lifespans.

Achieving healthy old age requires investments in health at every life stage. Healthy longevity begins in childhood, when access to healthcare resources are critical to ensure the development of a robust health foundation. Healthcare services from newborn screening to childhood vaccinations and programs to provide adequate nutrition help ensure the youngest generation launch on a favorable lifespan trajectory. Adolescence and early adulthood are marked by excess years of life lost due to suicide, substance abuse, and motor vehicle accidents,(CDC, 2019) highlighting the need for access to mental health and substance abuse services during this life stage. Sustaining good health in middle adulthood requires the timely

identification and management of chronic medical conditions, necessitating widespread access to reliable health services regardless of employment status. In later life, emphasis shifts toward sustaining functionality, optimizing quality of life, and minimizing morbidity. Each life stage presents unique needs and challenges to the healthcare system, requiring that healthcare providers and policymakers attend to the needs at each stage. Such an approach optimizes individuals ability to navigate a lifetime of health obstacles as they journey toward healthy old age.

In this report we discuss opportunities for growth in the American healthcare system that maximize healthy longevity. We start by providing an overview of the state of American healthcare, including a review of healthcare costs, outcomes, and insurance structures. We then transition to examining modalities for public health measurement, highlighting novel tools in measuring healthy longevity across diverse populations. A central tenet of the report will emphasize the measurement of healthspan, defined as the period of life in which one is in good health, which may offer a more robust measure of the overall health of a nation. Finally, the report will discuss innovations in healthcare delivery that provide opportunities to improve healthcare outcomes while reducing costs. Technological advances such as telemedicine and remote monitoring have taken a leap forward during the COVID-19 pandemic and provide optimism for cost-effective solutions that improve both the lifespan and the healthspan of our population.

Healthy longevity can be achieved while simultaneously driving down healthcare costs. Achieving such a goal will require the concerted effort of visionary policymakers, healthcare providers, economists, and public health experts. Two key opportunities for growth are development of a rigorous tool to measure healthspan in our population, and thoughtful deployment of telemedicine to broaden access to care.

Current State of American Healthcare

High spending and worse outcomes

The American healthcare system is the most expensive worldwide. In 2018 the U.S. federal budget allocated more money for healthcare (23%) than education (15%), the military (12%), or welfare (6%) (Office of Management and Budget, 2019). Healthcare consumes 17% of the national GDP, costing over $11,000 per person annually (*NHE Fact Sheet | CMS*, n.d.). By comparison, median per capita spending on healthcare by our peer nations falls between $2,000-2,500, as reported by the Organisation for Economic Co-operation and Development (OECD) (OECD, 2019). U.S. national healthcare expenditures are projected to continue growing in the face of an aging population and increasing prices for medical services (*NHE Fact Sheet | CMS*, n.d.). Growing healthcare costs are only accentuated on the backdrop of a shrinking U.S. economy due to COVID-19 (*Gross Domestic Product, 2nd Quarter 2020 (Second Estimate); Corporate Profits, 2nd Quarter 2020 (Preliminary Estimate) | U.S. Bureau of Economic Analysis (BEA)*, n.d.). U.S. healthcare premiums grow four times faster than the median earner's wages, with average premiums now costing $6,000 compared to a median salary of $33,700 (Sep 25 & 2019, 2019; U.S. Census Bureau, 1974).

High healthcare spending hurts our economy and depletes our national resources. Growing healthcare costs disproportionately consume societal resources leading to (1) limited economic growth both nationally and individually and (2) diminished resources available for important social programs. Citing concerns about growing healthcare costs impairing business growth, Warren Buffet called U.S. healthcare spending "a tapeworm on the economic system."(*Aetna CEO: "Warren Buffett Said Healthcare Was a Tapeworm on US Economy — It's True,"* n.d.) Per the Congressional Budget Office, as healthcare costs have grown, spending on discretionary programs including research and education have accordingly dropped (*Sequestration Update Report: August 2020 | Congressional Budget Office*, n.d.). Current U.S.

healthcare spending practices are neither sustainable, nor are they defensible when evaluating the healthcare outcomes appreciated.

Despite the most expensive healthcare system worldwide, the U.S. appreciates poorer health outcomes. In their landmark 2013 report, *Shorter Lives, Poorer Health,* the National Research Council detailed the healthcare outcomes in the U.S. as compared to 16 peer OECD nations. The U.S. consistently ranked toward the bottom in life expectancy, had higher death rates for a wide range of chronic conditions, excess years of life lost in youth, and higher rates of diabetes, hypertension, and obesity (National Research Council (US) & Institute of Medicine (US), 2013).

Poorer health outcomes are particularly pronounced in minority populations. Race and socioeconomic status have long been recognized to play critical roles in health-related outcomes(Egede, 2006), impacting life expectancy (Arias, Elizabeth, 2019), rates of obesity(Cossrow & Falkner, 2004; *Socioeconomic Status and Obesity | Epidemiologic Reviews | Oxford Academic*, n.d.), and morbidity and mortality from a wide range of chronic conditions(Cunningham, 2017). Healthcare disparities and institutionalized racism remain leading public health concerns in the U.S., impacting access to healthcare opportunities among racial minorities and negatively impacting wellness and longevity.(Cobbinah & Lewis, 2018; Paradies et al., 2015). Historical narratives inaccurately ascribe poorer health outcomes among racial minorities to behavioral or genetic factors, rather than identifying the underlying structural racism that impacts access to healthcare resources among minorities (Mays et al., 2007). Despite gains in life expectancy and improved outcomes across a variety of chronic conditions, African Americans have a lower life expectancy at birth of 75.3 years compared to Caucasian counterparts (78.8 years)(Arias, Elizabeth; Xu, Jiaquan, n.d.).

Though most pronounced in minority populations, worser health outcomes affect all segments of U.S. society. Studies have demonstrated that poorer health outcomes extend to every racial and socioeconomic group in the U.S. Age and socioeconomic status-matched

cohorts in the U.S. and United Kingdom found an increased burden of comorbidities, and worsened biomarkers in the U.S. at all socioeconomic status levels. Subset studies comparing non-hispanic whites in top socioeconomic brackets in the U.S. fared worse than their English counterparts (Banks et al., 2006).

The value of Affordable Health Insurance

Health insurance remains a touchstone cultural topic in America. Debates surrounding access and affordability of healthcare feature prominently in politics, news, and popular media. The cost of American health insurance is only matched by its complexity: hundreds of health insurers offer programs, including both employer and government-sponsored plans. Predominant among these is private, employer-sponsored health insurance, accounting for 179 million Americans, or 55% of the population. Medicare and Medicaid combined account for another 38% (Rosso, Ryan, 2021). The administrative costs of maintaining the American health care system are high: recent work estimates that administrative overhead consumes 34% of total healthcare costs, double the cost that is seen in Canada (Himmelstein et al., 2020).

Systematic reliance on employer-sponsored plans establishes a paradigm of the insurance haves and have-nots. Uninsured Americans appreciate shorter life expectancies and poorer overall health during their lifetimes (KIRBY & KANEDA, 2010), and employment status has been demonstrated to impact life expectancy(Rogot et al., 1992). Employment alone is not sufficient to ensure access to health insurance, and the U.S. Census Bureau estimates over 60% of the uninsured are currently employed (United States Census Bureau, n.d.). Access to health insurance has only grown more complex during COVID-19, when record unemployment contributed to unprecedented losses in health insurance nationwide (Anuj Gangopadhyaya and Bowen Garrett, 2020). Under our current system, the negative impact of an economic downturn is compounded by the damage unemployment has on access to medical care, overall health, and lifespan across our population.

Disparities in healthcare outcomes are reflected in insurance status among racial minorities. African Americans are nearly twice as likely to be uninsured. An estimated 9.3% of African Americans are uninsured, nearly double what is seen in non-Hispanic whites (5.2%).(Berchick, Edward; Barnett Jessica; Upton Rachel, 2019). Africans Amerians pay twice as much of their household income on health insurance premiums. African American families spent almost 20% of household income for healthcare premiums, almost double the national average of 11% (*Racism, Inequality, and Health Care for African Americans*, 2019).

The last decade has witnessed a fundamental shift in healthcare accessibility in the U.S. With the enactment of the Affordable Care Act (ACA) in March of 2010, the U.S. embarked on a historic national experiment in redefining widespread access to healthcare. The ACA law included three primary goals: (1) making health insurance accessible to more people by providing insurance subsidies to households earning between 100-400% of the federal poverty level, (2) expanding Medicaid access, and (3) promoting the use of innovative care systems that targeted lowering healthcare expenses (Office of the Legislative Council, 2010). As a result of these interventions, the last decade has seen unprecedented gains in health insurance coverage in the U.S., allowing policymakers to assess the impact of the ACA on both economic and health-related outcomes.

Studies of the ACA have consistently demonstrated its beneficial impact. In addition to delivering on the promise of increased access to healthcare, the ACA has been associated with unprecedented drops in cost and simultaneous improvements in quality as measured by decreasing rates of readmission and hospital acquired conditions (Blumenthal et al., 2015). With a decade of experience under the regulations required by the ACA, public health scientists have found that increased access to affordable healthcare leads to less uninsurance, more contact with preventative health services, and better self-reported health outcomes:

- Study of states that expanded Medicaid under ACA found 8.2% less uninsurance, decrease in reports of inability affording medical care; however

no change in rate of physician visits or overnight hospital stays.(Miller & Wherry, 2017)

- Three year follow up of the ACA demonstrated that uninsured people gaining health coverage had a 41% increase in finding a "medical home", a reduction in out-of-pocket spending of $337, increase in preventative health visits, and 23% increase in self-reporting health as "excellent".(Sommers et al., 2017)
- Dependents covered by parents health insurance as part of the ACA act were more likely to have contact with a PCP, to have excellent self-reported health, and to have a lower BMI.(Barbaresco et al., 2015)
- Implementation of ACA resulted in lower uninsured rates among minorities (7% drop in uninsured rates among African Americans, and 5% drop in Latinx), and that patients were more likely to have physician visits and less likely to delay care.(Chen et al., 2016)

The long-term benefits of expanded healthcare access will take decades to fully materialize. As Americans gain access to necessary health services at all life stages, their health foundation and longevity trajectory have been positively impacted. Improved access to preventive services will reap rewards for public health in longevity and quality of health for years to come. The challenge will be in measuring those expected benefits prospectively.

Measuring the Impact of Public Health Measures

Accurately measuring the health of a population has been a long-standing challenge in public health. No available public health tool can answer the question that sits at the heart of all healthcare and public health endeavors: how long can an average person expect to live in good health? As healthcare costs have grown, increasing attention has turned to innovations intended to lower costs while improving the quality of healthcare delivered. Among these interventions include broad sweeping approaches such as the ACA, as well as narrower interventions targeted to particular populations. Key to understanding the efficacy of any public health intervention, regardless of scope, is the ability to assess that intervention's impact. In this section we review some of the commonly used public health tools for measuring population health, as well as the limitations associated with each (Accounts, 2010).

Methodologies and challenges in measuring population health

Life expectancy: Arguably the most visible public health measure, life expectancy captures an actuarial estimate of lifespan derived from tables of age-specific mortality rates across a population. As life expectancy is derived from historic mortality rates, it generally provides an underestimate of the true lifespan expected for newborns. Further, life expectancy does not consider the age distribution within a population and therefore cannot inform estimates of per capita healthcare spending necessary for healthcare system and budget design.

Condition-related morbidity: A variety of condition and organ specific measures have been trialed to assess the morbidity and mortality associated with a range of chronic conditions. Such measures are limited however in their usefulness as a tool for assessing population health: the multitude of medical conditions present raises difficulties in comparing health-related measurements across conditions, and there is no straight forward approach to aggregating scores for individuals suffering from more than one condition.

Health-related Quality of Life (HRQoL): Health-related quality of life describes a set of interrelated measures that are designed to provide an aggregate score of population-wide health that includes (1) morbidity and mortality for multiple health conditions, and (2) individual self-reported health and wellness. Drawbacks have included the proprietary nature of many of these measures, burden in acquiring all the information needed to perform the measurement, and difficulty interpreting and comparing the resulting complex, multidimensional scores.

Quality Adjusted Life Year (QALY): A measure of disease burden as derived by aggregate HRQoL measures, where 1 QALY is equivalent to one year of perfect health. QALYs gained by virtue of a particular healthcare intervention can be ranked through use of an incremental cost-effectiveness ratio, allowing for the most beneficial services to be selected for funding. Concerns have arisen whether the measures reflected in QALY measurement reflect the health preferences of the populations under study, and whether use of QALYs alone to determine funding preferences is equitable as QALY measurements discount the value achieved in older and sicker populations.(Weinstein, Milton C, Torrance, George, McGuire Alistair, 2009)

Quality Adjusted Life Expectancy (QALE): QALE captures a measure of life expectancy adjusted for quality of life as captured by HRQoL surveys. Similar to life expectancy measurements, QALE uses historical data to estimate expectancy, and accordingly provides an underestimate of quality years expected. While QALE measurement comes close to addressing the healthspan of a nation, there are certain limitations in the measurement of QALE that we must consider: (Accounts, 2010)

(1) *Snapshot assessment of current health that underestimates longevity:* By definition, QALE uses historic data to provide a current estimate of life expectancy assuming no future changes in disease burden take place. This approach eases the burden of data collection, however it should be noted that QALE calculation remains a data-intensive process. Given use of historic data, QALE measurement does not consider trends toward improvement in longevity and uptake of preventative measures, as brought about by the ACA. Accordingly, measurements of QALE will provide underestimates of future health.

(2) *Discounts benefit of preventive services and risk factor reduction:* As a measure of current health, QALE does not consider the longer-term benefit of preventive services or reducing risk factors that impact health such as smoking. In fact, given the increased cost, and potential side effects associated with preventive healthcare, QALE measurement may rate these services negatively despite a longer-term beneficial impact (i.e. an abnormal mammogram necessitating a biopsy for what is found to be a benign lesion, even though mammograms as a service reduce morbidity for the population).

(3) *Does not consider non-medical dimensions of health:* QALE measurements draw on HRQoL measures to derive a measure of self-reported health status. Presently no measure exists that incorporates elements such as well-being, mental health, and social health, nor addressing the burden of financial and behavioral aspects.

Healthspan as an Emerging Public Health Tool

A complex healthcare system serving a heterogenous population demands nuanced means of measuring public health. One-size-fits-all, retrospective measurements do not adequately capture the interplay of multiple life domains on lifespan. An individual's mental health, access to employment, social interconnectedness all influence their life course

trajectory, and will vary based on demographic factors. In this context, one may consider the development of a novel public health measurement tool that reflects the same complexity and nuance of the populations it measures. In this section of the report we will discuss the attributes of such a public health measure that has been proposed, called “healthspan”.

Healthspan is a novel public health measure to assess healthy longevity. Healthspan is defined as “the period of life spent in good health, free from the chronic diseases and disabilities of aging” (Kaeberlein, 2018). Accordingly, healthspan serves to capture not only the length of life, but also its quality across multiple health-related factors. One could expand the definition further to incorporate elements of overall wellness, including security in employment, finances, housing, food, and social interconnectedness. In this way, healthspan measurement serves as a natural complement to the “compression of morbidity” hypothesis (Fries, 1980). In compression of morbidity, public health interventions are targeted to reduce the duration and burden of medical infirmity toward the tail end of the natural lifetime (Fries, 2005). Healthspan measurement serves as a positive complement, assessing the duration of healthy life that is appreciated across different demographics amongst our population.

As with other measures of public health, healthspan is a multifaceted measure. An ideal measure of healthspan would include health-related outcomes as central features, however would also incorporate the multitudinous facets that are integral to leading a healthy and fruitful life. Such measures would include access to education, employment, financial security, safe housing and environments, social networks, and behavioral factors that all impact wellness. Healthspan offers the following potential benefits over existing public health measures:

(1) **Differentiate between healthspan and lifespan:** A key trait of healthspan measurement will be the ability to assess not only the years of lifespan gained in a population, but the overall quality of life that was enjoyed. Accordingly, public

health interventions that promote lifespan without promoting healthspan may not be as appealing as interventions that augment both. Further, interventions may be identified that only promote healthspan without significantly impacting lifespan, thereby reducing the burden of disability and infirmity faced by a population. For example, the recent introduction of varicella (a.k.a chicken pox) vaccination among children has resulted in a decrease in incidence of shingles within this age group (Weinmann et al., 2020). Such an intervention may additionally prevent shingles incidence in later adulthood, thereby mitigating a source of morbidity and improving overall healthspan of vaccinated groups.

(2) **Uniformity of measurement:** Measured appropriately, healthspan offers a powerful tool in promoting public health across all demographics. Evaluation of how a particular service promotes healthspan could serve as a uniform measuring stick across which multiple healthcare services could be gauged. "Added healthspan" could be used to assess the efficacy of various public health measures, and in determining when and where public health funding should be directed**.** Such measurement of healthspan-prolonging interventions can be applied across an entire population (i.e. an entire nation), or can be targeted to particular demographic groups within a population. Measurement of healthspan of different demographic groups will be essential to identify healthspan disparities, and accordingly select targeted interventions to best address those disparities. For example, a recent Medicare program targets improved treatment pathways for patients with end-stage renal disease by updating payment models to promote patient access to home dialysis and kidney transplantation (*CMS Announces Transformative New Model of Care for Medicare*

Beneficiaries with Chronic Kidney Disease | *CMS*, n.d.). Such a model offers the opportunity to improve healthspan within a medically vulnerable population while simultaneously reducing healthcare expenditures.

(3) **Address systemic inequity:** Healthy longevity in our nation can only be achieved by addressing the disparities that impact minority populations. Healthspan measurement can be leveraged to ensure equitable access to healthcare across all populations, and to promote healthy longevity for all Americans. It should also be noted that current healthcare disparities are as reported by historic public health measures, and may represent an underestimate of the true losses in healthspan seen in minority groups. Accurate healthspan measurement could give us a new perspective on healthcare disparities in the U.S. and could provide a novel lens to evaluate the disparities that impact our communities and to design interventions to address those issues.

(4) **Consider health as a non-binary variable:** For the majority of people, health-status will fluctuate over their lifetime, with stretches of relative good health interrupted by episodes of relative disability. Further, the definition of “good health” is a relative concept open to interpretation, and definitions will vary from individual to individual. The ability for an external observer to accurately determine another person’s perceived health status is fraught with error (Krahn et al., 2009), and ultimately an argument can be made that only the individual can best assess their relative health. In this context, one may consider that health status is not a binary variable, i.e. one’s perceived health status more likely reflects a multifaceted measurement with shades of grey in each dimension. Accordingly, healthspan measurement must reflect this added complexity. One may consider

an “area under the curve” of health over a lifetime for an individual across the many dimensions of health. Ie. mental health may wax and wane separate from physical health, which itself may fluctuate separately from financial, employment, and behavioral health. Aggregate measures across populations could further our understanding of how perceived health varies over lifetimes and across demographics.

Healthspan as a measurement tool is not free from limitations. Careful consideration of the pitfalls of any public health measurement tool is essential to ensure that unintentional bias does not impact measurement and disadvantage the populations it is intended to serve. Limitations in healthspan measurement include and are not limited to the following: (1) Subjectivity of the measure: Different people with the same comorbidity burden may perceive their health very differently; (2) Fluidity of perceived health over time: Health is a fluid concept: people will go through periods of poor health followed by recovery; (3) Varying importance of differing health measures across demographics: a the multiple dimensions impacting wellness are expected to vary by individual and across different demographic groups, reflecting the complex interplay of societal, cultural, and religious factors on perceived health status.

Achieving healthy longevity requires that the right health intervention be deployed at the right life stage. As our healthcare system faces financial constraints, health care providers and policymakers are faced with decisions regarding which health services to prioritize on a population level. Further, in addition to choosing *which* intervention to implement, policymakers must choose *when* in the life course to deploy said intervention. Measurement of healthspan allows for thoughtful implementation of the right intervention during the right life stage to optimize a healthy life trajectory. Put another way, healthspan measurement may offer answers to the question of when in the lifespan to deploy selected interventions in order to maximize healthspan. For instance, the U.S. Preventive Services Task Force recommendations target

specific health interventions to particular age groups in order to maximize the cumulative beneficial impact. Per the USPSTF recommendations for preventive health screening vary by age, demographics, history of high risk behaviors such as smoking, and pregnancy status, among others. Such an approach highlights the potential strengths of targeted preventive health interventions, and serves as a blueprint for how additional interventions could be developed that further target disadvantaged populations.

Healthcare Systems that Promote Healthy Longevity: Telehealth in the U.S. Healthcare System

The digital age has transformed medicine. With the advent of electronic medical record systems, digitization of medical imaging, and development of robotic-assisted surgery, the field of medicine has undergone fundamental changes in how healthcare is delivered. These innovations pale in comparison with the scope of change expected to be seen as telemedicine services sweep into the mainstream. Long stymied by overly restrictive federal regulations and absent reimbursement options, telemedicine has now appreciated a renaissance in the era of COVID-19. With the remarkable proliferation of personal computers and smartphones throughout our population (*U.S. Smartphone Penetration Surpassed 80 Percent in 2016*, n.d.), there is now a demand for, and an opportunity to deliver on the aspirational goal of bringing state-of-the-art healthcare to the home of every American. COVID-19 has served as a catalyst of bringing telemedicine into the mainstream. Hospital systems have rapidly brought telemedicine services to scale (Mann et al., 2020), and many expect telemedicine to become a part of routine medical care moving forward. In this section of the report we review the opportunities present in the widespread implementation of telemedicine services.

Telemedicine describes a suite of services for providing healthcare outside of the traditional hospital setting. Though available for years, the widest uptake of telemedicine has only been seen recently in the face of COVID-19 (Keesara et al., 2020). Telemedicine services

are most widely associated with Zoom calls with healthcare providers; the full range of services, however, is far greater. In its broadest definition, telemedicine includes provision of remote healthcare delivery in any format, whether through video and telephone visits, online health portals, or smart devices for remote biometric monitoring. Widespread use of telemedicine has revolutionized the healthcare systems ability to deliver specialty services, particularly to rural locations and underserved populations.

Telemedicine offerings are as varied as the myriad personal electronic devices now present in U.S. homes. Telemedicine services can be divided into *synchronous* services, or services where both the patient and provider are interacting in real time, typically through live videoconferencing, or *asynchronous*, in which patient data is "stored-and-forwarded" for provider review at a later point (*Telemedicine and Telehealth | HealthIT.Gov*, n.d.). The applications for telemedicine are multitudinous and include the following:

- *Virtual visits:* Describe healthcare services administered via synchronous, audio-visual video or telephone conferencing modalities (i.e. Zoom, WebEx, Doximity App, FaceTime). Allows for multiparty conferences to connect the patient and provider, as well as relevant additional parties such as family members, medical interpreters, medical trainees, and ancillary healthcare staff.

- *Specialty care:* Acute care hospitals, particularly in rural areas, have benefited from remotely consulting specialty services typically only available at referral centers. Telestroke serves as a model example: hospitals supplement available neurologic resources with a telestroke tool, whereby a neurologist at a referral center can guide acute stroke management, allowing for safe administration of urgent stroke therapies and timely transfer to a higher level of care (Kepplinger et al., 2016). Similar services

have been implemented successfully in critical care (Lilly et al., 2011) and emergency medicine. Mueller et al., 2014).

- *Specialist interpretation:* Remote interpretation of digital radiology (*Teleradiology - an Overview | ScienceDirect Topics*, n.d.), digital pathology (Weinstein et al., 2001), and electrocardiograms (ECGs) in myocardial infarction (Brunetti et al., 2017) have all been described, leveraging the scope of practice of specialty physicians to better serve a larger catchment area, and allowing for early triage of time-sensitive conditions.

- *Health dashboards:* Healthcare systems are increasingly integrating with smartphone applications and web-based products to offer patients health dashboards where patients can access their medical chart including their appointment schedule, medical results, and physician notes. Advanced dashboards allow patients to cancel or reschedule appointments, and send electronic messages to their provider teams.

- *Smart devices:* A wide array of devices have come to market over the last decade for health and fitness monitoring: wearable devices track steps, monitor heart rate, and record sleeping patterns; contactless devices record vital signs in the home setting; and smartphone apps integrate with smart devices to report data trends.

As telemedicine services proliferate, they grow in popularity and uptake. Studies of telemedicine have shown these services to be feasible, clinically effective, and well-received by patients. A review of telemedicine meta analyses evaluating the effectiveness, patient tolerance, and cost effectiveness of these services are briefly summarized below. While considering the literature on telemedicine it is worth noting that available studies reflect practices at least 5-10 years out of date. Given the rapid advancement of health technologies,

and growing penetrance of technology into the homes and lives of average Americans, it stands to reason that the efficacy of telemedicine will only improve. This would reflect the experience seen with telemedicine in the era of COVID-19, when sweeping uptake of telemedicine services was seen nationwide, accompanied by growing acceptance of telemedicine, and even preference for virtual services (Hollander & Carr, 2020).

- *Efficacy:* Telemedicine has proven efficacious and efficient in the treatment of a range of interventions, including chronic condition management, smoking cessation, and telepsychiatry services. Though early studies have been promising, these effects have not been seen consistently across all populations and interventions studied (Ekeland et al., 2010).
- *Patient tolerance:* Telemedicine has been shown to achieve equal to improved patient satisfaction.(Agha et al., 2009; Mair & Whitten, 2000) During COVID-19, patients have expressed a preference to transition to virtual visits(Duffy & Lee, 2018), particularly in light of social distance requirements and a desire to avoid the healthcare setting.
- *Cost effective:* Studies remain equivocal on the cost effectiveness of telemedicine interventions, limited by small sample size and absence of robust analysis of conventional versus remote care delivery (de la Torre-Díez et al., 2014; Mistry, 2012; Whitten et al., 2002). Arguably with the introduction of novel reimbursement structures that favor telehealth services over the last several years, the economic efficacy will additionally become apparent.

Telemedicine and the Digital Divide

With the widespread uptake of telemedicine services, new healthcare disparities have arisen. As healthcare services have increasingly turned toward remote, virtual visits, a new medically vulnerable population has taken shape: those without adequate internet access. The Digital Divide has long been recognized in the U.S., separating those with affordable and reliable internet access from those without. The National Digital Inclusion Alliance (NDIA) estimates that nearly a third of US households in medium and large cities do not have broadband internet access, including an estimated 11% of households without any internet connectivity whatsoever, including mobile plans (*Definitions*, 2017). Barriers to internet access are especially pronounced amongst racial minorities, with recent studies estimating that 36% of Black households have no internet connectivity, as compared to 21% among White households (Bureau, n.d.). Also impacted include older populations and those living in rural, low-income areas where nearly a quarter of people lack in-home internet connectivity (*Eighth Broadband Progress Report*, 2012).

Internet access during the time of COVID-19 is especially perilous. With the widespread closure of schools, libraries, and coffee shops, previously accessible public internet access points are no longer available. This leaves an estimated 100 million Americans without access to broadband internet in their home, including an estimated 19 million whose neighborhoods lack the required infrastructure for broadband at all. The effects of the digital divide have never been more acutely felt than in the present moment, when access to essential services such as healthcare and education hinge on in-home connectivity.

Telemedicine and Healthspan: A role for Artificial Intelligence

Telemedicine services will enrich our understanding of healthspan on a population level. With the advent of new wearable and in-home monitoring devices, the scope of health data that can be collected and monitored will only grow. Supplemented by the explosion in telemedicine services, the era of virtual health monitoring, and the accompanying data collected, is only in its infancy. Electronic health data is being recorded and stored on a scale never seen before: public health offices track and monitor diseases, electronic medical record systems store troves of patient data, and smart devices monitor individual-level biometrics and activity level with tremendous granularity. Measurement of healthspan will be enriched by integrating these many sources of health data becoming available, allowing for a better understanding of individual and population-level patterns. Advances in artificial intelligence and deep neural networks suggest that the interpretation of such troves of data is within our reach, and that our healthcare system should be prepared to harness the power of the tools in development. A digitized healthspan tool would be equipped to consolidate and interpret disparate sources of information to recognize trends and offer predictive analytics based on population characteristics. Such a technological breakthrough will greatly empower policymakers and public health experts to more effectively assess healthspan in real time and influence the health trajectory of our populations.

The incredible volume of data being generated and recorded is offset by the difficulty in synthesizing all these disparate data sources: instead, data has been siloed into individual health care systems or stored locally on various devices. A uniform clearinghouse of data would be required to ensure that health-related data, whether from a hospital's electronic medical record or an individual's personal Fitbit, could be synced to allow for broader interpretation. Another consideration, as well, is ensuring the privacy and security of the data collected. Individual-level data and predictive analytics should be treated with the same sensitivity as health data, ensuring that individuals have control over who has access to their data. For instance, data pertaining to one's lifestyle and behavioral choices could impact an individual's

eligibility to purchase insurance, qualify for a loan, secure employment, or engage in other pursuits.

Impact of COVID-19 on the American Healthcare system

The COVID-19 pandemic has brought about a rapid and fundamental shift in healthcare delivery. In the spring of 2019, healthcare systems faced unprecedented circumstances including overwhelmed emergency and inpatient services, inadequate supplies of masks and other personal protective equipment, shortages of ventilators and other life support tools, and the stresses of a medical workforce risking exposure to a novel pathogen. While the long-term sequelae of the COVID-19 pandemic on the healthcare system remain to be seen, experiences to date have exposed cracks in the foundation of how our nation delivers healthcare:

(1) **Difficulty scaling medical services:** As evidenced by experiences in New York City, Wuhan City, and Lombardy Italy, hospital systems were rapidly inundated with patients. Capacity limitations meant that only the sickest patients could receive care, with the remainder monitoring symptoms outside of the hospital setting.(Remuzzi & Remuzzi, 2020)

(2) **Tenuous hospital revenue sources:** COVID-19 has revealed a paradox of hospital reimbursement: despite being desperately busy with sick patients, hospitals nationwide have been losing money. This seeming contradiction can be explained when considering the disproportionately high reimbursement allotted for elective surgical procedures. With widespread elective procedure cancellations, hospitals forfeited over 30% of their cumulative revenue, placing smaller rural hospitals at risk of closure.(Khullar et al., 2020)

(3) **Overreliance on employer-sponsored health insurance:** Over the last decade, about half of the U.S. population has received insurance through their

employer.(“Health Insurance Coverage of the Total Population,” 2019) In the face of historic unemployment rates during COVID-19, more Americans than ever are facing gaps in their health coverage.(*Current Unemployment Rates for States and Historical Highs/Lows*, n.d.) The loss in health quality brought about by delaying or avoiding needing preventive and other medical services will take years to manifest.

The threats to the healthcare system posed by COVID-19 offer compelling opportunities for growth and change in our healthcare system. Chief among these novel possibilities arises the need for an urgent transition to telemedicine. Telemedicine offers the opportunity to expand healthcare system capacity and revenue sources while simultaneously meeting the needs of the population. An efficient and effective transition to telehealth will require health systems to rapidly scale existing telehealth systems (Hollander & Carr, 2020). In the post-COVID era there has been an irreversible shift in the balance, now favoring use of virtual services for the provision of remote healthcare.

Summary

Achieving healthy longevity requires investments at every life stage. Early access to preventative healthcare, prenatally and in early childhood, can have lasting effects that positively impact a lifetime of better health. Lifespan is a product not only of health, but also of zip code, socioeconomic status, race, and access to healthcare, employment, and financial security. A more equitable society would level the playing field, ensuring opportunity for healthy longevity regardless of demography. As U.S. life expectancy lengthens, our healthcare system must be reimagined to sustainably provide high-value, cost-effective care for the duration of our lifespans.

The US healthcare system is expensive and inefficient in care delivery, with particular heterogeneity in access to care noted among vulnerable populations. Despite this, opportunities for improvement exist, including a fundamental shift to focusing on healthspan of a population rather than lifespan, and implementation of novel health-related technologies such as telemedicine.

No one measure of population health can completely and accurately capture the health of a nation. Making prudent societal choices in the face of limited, and imperfect data is a central challenge facing public health experts and policymakers alike. Not only will healthcare interventions require iterative improvement to maximize their benefit, but the tools that we use to measure public health themselves require iterative improvement and reassessment. Our society can take stock of where our healthcare investments are being made, and reimagine how those resources are used to promote.

Achieving longevity in the U.S. mandates addressing the underlying systemic issues that impacts minority groups to ensure they benefit. This includes development of tools that can identify health disparities among vulnerable populations, and the implementation of public health programs that address those disparities. Among these opportunities include addressing and closing the digital divide amongst racial minorities, ensuring access to in-home broadband internet connectivity regardless of demographic or location.

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