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Digital Medical Tools and Sensors

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Until now, most of the effect of the digital era in the practice of medicine has been confined to electronic health records. But that is about to undergo a radical transformation in the next 5 years.

Moore's law, the prediction in 1965 that there would be a doubling of transistors in a chip every 2 years, has relentlessly marched on. Now, in parallel, there is a doubling every 5 years of the number of mobile devices connected via the Internet, leading to approximately 50 billion in 2020[1] (Table). This leads to the projection that in the next 5 years there will be almost 7 connected devices per individual. Part of the exponential growth of the Internet of Things (advanced interconnectivity between systems and services) comprises sensors, which are increasingly being embedded into smartphones and wearable devices. That it is now possible to pack 19 million transistors into 16 nm explains how there are more than 2 billion transistors in some current smartphone models. It is not just about the hypercompression of transistors into integrated circuits; it is the remarkable decline in cost. That combination has led to smartphones that cost $35 with all the essential capabilities of the ones that are priced at more than $500 and to the projection that more than 90% of all individuals in the world older than 6 years will have a mobile phone device by 2020.[2]

Although traditionally, DNA sequencing has been seen as a separate domain from digital, that certainly cannot be sustained. Not only are some sequencing platforms chip based, and

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the A, C, T, and G nucleotides seamlessly represented by 0|1 digitally, but the extensive processing of the data fully relies on computing. All of this in silico progress has laid the foundation for whole-genome sequencing to reach the $1000 threshold, along with the newfound ability to perform this assay and point-of-care testing in millions of individuals over the next 5 years.

It has only been 1 decade since the founding of Facebook, which has now assembled more than 1.3 billion users and has surpassed China as the largest community of people in 2014. It is only 8 years since cloud computing was invented; quickly it has become pervasive. The speed of supercomputers has increased by several orders of magnitude in recent years, now up to 55-petaflop (processing speed of 10^{15} floating-point operations/second) and soon to reach exaflop (processing speed of 10^{18} floating-point operations/second) velocity.[3]

When and how will all this tectonic tech progress finally come to clinical care? Current devices have achieved the capability of digitizing a human being with the use of wearable sensors to quantify physiologic metrics such as vital signs or relevant aspects of a person's environment, imaging to provide high definition of the anatomy, sequencing of the individual's germline DNA, RNA, microbiome, and the epigenome to elucidate an individual's biology.[4] Such progress has already reshaped the field of prenatal testing, with nearly 20% of pregnant mothers in the United States now undergoing first trimester fetal DNA sequencing via a single tube of blood for very early and accurate diagnosis of chromosomal aberrations.[5] Sequencing has been used to establish the molecular diagnosis of an increasing number of individuals with a serious, undiagnosed, unknown medical condition for a fraction of the cost of multiple medical workups that have been standard for these "diagnostic odysseys." Sequencing of the pathogen has been critical to responding to serious infections outbreaks or saving the lives of individuals when root cause determination through traditional means has failed. However, sequencing has not yet been used at any scale for most potential indications in clinical practice, including management of cancer from the initial diagnosis, or matching prescription medications and doses with each individual's pharmacogenomic profile.[4]

In contrast, in US daily smartphone-centric existence, sensors have already been used for activity tracking by more than 1 in 4 in dividuals.[5] Although use of sensors is typically not durable, this represents an important precedent for potential adoption. Food and Drug Administration–approved smartphone electrocardiogram sensors are already available to consumers and include immediate computer-assisted readings. Likewise, suspicious skin lesions can be algorithmically diagnosed via a smartphone camera, with the image sent to a cloud server, with accuracy equivalent to or exceeding that of physicians.[6] In the next 5 years, blood pressure and glucose levels could be continuously monitored via a smart watch for individuals with hypertension and diabetes, respectively. Soon, most routine laboratory tests will likely be obtainable by consumers with smartphone kits. Furthermore, much of the physical examination can now be performed remotely with digital devices, and smartphone-based imaging tools, including ultrasound, are being developed for any individual to obtain relevant anatomic data.[5]

Although these digital medical tools are being rapidly developed to capture an extraordinary array of information, healthcare has not kept up with processing the torrent of data or its security. Ultimately, if each individual's data are fully integrated and analyzed, there is the potential to develop virtual health assistants that build substantially upon the beginning of artificial intelligence in today's contextual computing (such as Google Now, Apple Siri, or Microsoft Cortana). It is easy to envision that predictive analytics using all the relevant metrics for an acute event, such as an asthma exacerbation, seizure, heart failure decompensation, severe depression, or autoimmune disease symptoms, could warn individuals and their physicians before these events occur.[5] Yet such progress will not likely be deemed acceptable without ensuring that the individual's data are not being sold or breached. In the next half of this decade, as much attention must be paid to deep medical learning to preempt illness as to data security to protect the privacy of individuals.

The "dataization" of an individual's medical essence—what makes people tick—establishes other important new opportunities and challenges. While transforming medicine into a data science, there is a legitimate concern that physicians will be too datacentric and miss the vital and intimate connection—the human touch—with their patients. Further, with data flowing directly to the patient through mobile devices, there will likely be a significant change in the patient-physician relationship. Much of the diagnostic and monitoring functions performed by physicians today can be offset to computers and algorithms for patients. Improvement in diagnostic accuracy by physicians could likely be facilitated by synapses with supercomputers. Hospital rooms could be replaced by remote monitoring via the patient's bedroom; many office visits could be changed from physical to virtual.

Besides the chance to reduce the enormous economic toll of current practice, perhaps the greatest windfall from Moore's law coming to medicine will be the massive collation of granular data for each individual into new information resources. Whether for cancer, hypertension, diabetes, autoimmune conditions, or any significant illness, the new information at a population level may greatly increase current understanding and optimize management for subsequent affected or at-risk individuals. However, for all such changes to occur, it will take a new plasticity of the medical community in facing its greatest and singular challenge since the profession's origin—its transformation by pervasive embracement of digital technology.

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Table

The Digitally Connecting World 2010–2020

	2010	2015[a]	2020[a]
World population, billion	6.8	7.2	7.6
No. connected			
Devices, billion	12.5	25	50
Devices per person	1.8	3.5	6.6
No. of smartphone subscriptions, billion	0.5	3.0	6.1
No. of wireless hotspots, million	3	47	500
No. of transistors, million/chip, nm	16/40	19/16	22/8
No. of sensors	20 Million	10 Billion	1 Trillion
No. of individuals sequenced	<10	400 000	5 Million

[a]Numbers represent estimates based on literature.[5]