The Healthcare Singularity and the Age of Semantic Medicine

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In 1499, when Portuguese explorer Vasco da Gama returned home after completing the first-ever sea voyage from Europe to India, he had less than half of his original crew with him—scurvy had claimed the lives of 100 of the 160 men. Throughout the Age of Discovery,[1] scurvy was the leading cause of death among sailors. Ship captains typically planned for the death of as many as half of their crew during long voyages. A dietary cause for scurvy was suspected, but no one had proved it. More than a century later, on a voyage from England to India in 1601, Captain James Lancaster placed the crew of one of his four ships on a regimen of three teaspoons of lemon juice a day. By the halfway point of the trip, almost 40% of the men (110 of 278) on three of the ships had died, while on the lemon-supplied ship, every man survived [1]. The British navy responded to this discovery by repeating the experiment—*146 years later.*

In 1747, a British navy physician named James Lind treated sailors suffering from scurvy using six randomized approaches and demonstrated that citrus reversed the symptoms. The British navy responded, 48 years later, by enacting new dietary guidelines requiring citrus, which virtually eradicated scurvy from the British fleet overnight. The British Board of Trade adopted similar dietary

[1] 15th to 17th centuries.

practices for the merchant fleet in 1865, *an additional 70 years later.* The total time from Lancaster's definitive demonstration of how to prevent scurvy to adoption across the British Empire was 264 years [2].

The translation of medical discovery to practice has thankfully improved substantially. But a 2003 report from the Institute of Medicine found that the lag between significant discovery and adoption into routine patient care still averages 17 years [3, 4]. This delayed translation of knowledge to clinical care has negative effects on both the cost and the quality of patient care. A nationwide review of 439 quality indicators found that only half of adults receive the care recommended by U.S. national standards [5].

THE IMPACT OF THE INFORMATION EXPLOSION IN MEDICINE

Despite the adoption rate of medical knowledge significantly improving, we face a new challenge due to the exponential increase in the rate of medical knowledge discovery. More than 18 million articles are currently catalogued in the biomedical literature, including over 800,000 added in 2008. The accession rate has doubled every 20 years, and the number of articles per year is expected to surpass 1 million in 2012, as shown in Figure 1.

Translating all of this emerging medical knowledge into practice is a staggering challenge. Five hundred years ago, Leonardo da Vinci could be a painter, engineer, musician, and scientist. One hundred years ago, it is said that a physician might have reasonably expected to know everything in the field of medicine.[2] Today, a typical primary care doctor must stay abreast of approximately 10,000 diseases and syndromes, 3,000 medications, and 1,100 laboratory tests [6]. Research librarians estimate that a physician in just one specialty, epidemiology, needs 21 hours of study per day just to stay current [7]. Faced with this flood of medical information, clinicians routinely fall behind, despite specialization and sub-specialization [8].

The sense of information overload in medicine has been present for surprisingly many years. An 1865 speech by Dr. Henry Noyes to the American Ophthalmologic Society is revealing. He said that "medical men strive manfully to keep up their knowledge of how the world of medicine moves on; but too often they are the first to accuse themselves of being unable to meet the duties of their daily calling…." He went on to say, "The preparatory work in the study of medicine is so great, if adequately done, that but few can spare time for its thorough performance…." [9]

[2] www.medinfo.cam.ac.uk/miu/papers/Hanka/THIM/default.htm

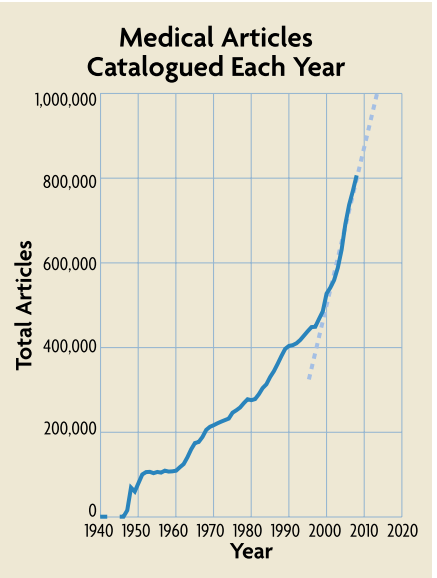

FIGURE 1.
The number of biomedical articles catalogued each year is increasing precipitously and is expected to surpass 1 million in 2012.

COULD KNOWLEDGE ADOPTION IN HEALTHCARE BECOME NEARLY INSTANTANEOUS?

The speed at which definitive medical discoveries have broadly reached medical practice over the last two millennia has progressively increased, as shown in Figure 2 on the next page.

Focusing on the last 150 years, in which the effects of industrialization and the information explosion have been most acute, the trajectory flattens slightly but remains largely linear, as the figure shows. (An asymptotic fit yields an r^2 of 0.73, whereas the linear fit is 0.83.)

Given that even the speed of light is finite, this trend will inevitably be asymptotic to the horizontal axis. Yet, if the linearity can be sufficiently maintained for a while, the next 20 years could emerge as a special time for healthcare *as the translation from medical knowledge discovery to widespread medical practice becomes nearly instantaneous.*

The proximity of this trajectory to the axis occurs around the year 2025. In response to the dramatic computational progress observed with Moore's Law and the growth in parallel and distributed computing architectures, Ray Kurzweil, in *The Singularity Is Near*, predicts that 2045 will be the year of the Singularity, when computers meet or exceed human computational ability and when their ability to recursively improve themselves can lead to an "intelligence explosion" that ultimately affects all aspects of human culture and technology [10]. Mathematics defines a "singularity" as a point at which an object changes its nature so as to attain properties that are no longer the expected norms for that class of object. Today, the dissemination path for medical information is complex and multi-faceted, involving commercials, lectures, brochures, colleagues, and journals. In a world with nearly instantaneous knowledge translation, dissemination paths would become almost entirely digital and direct.

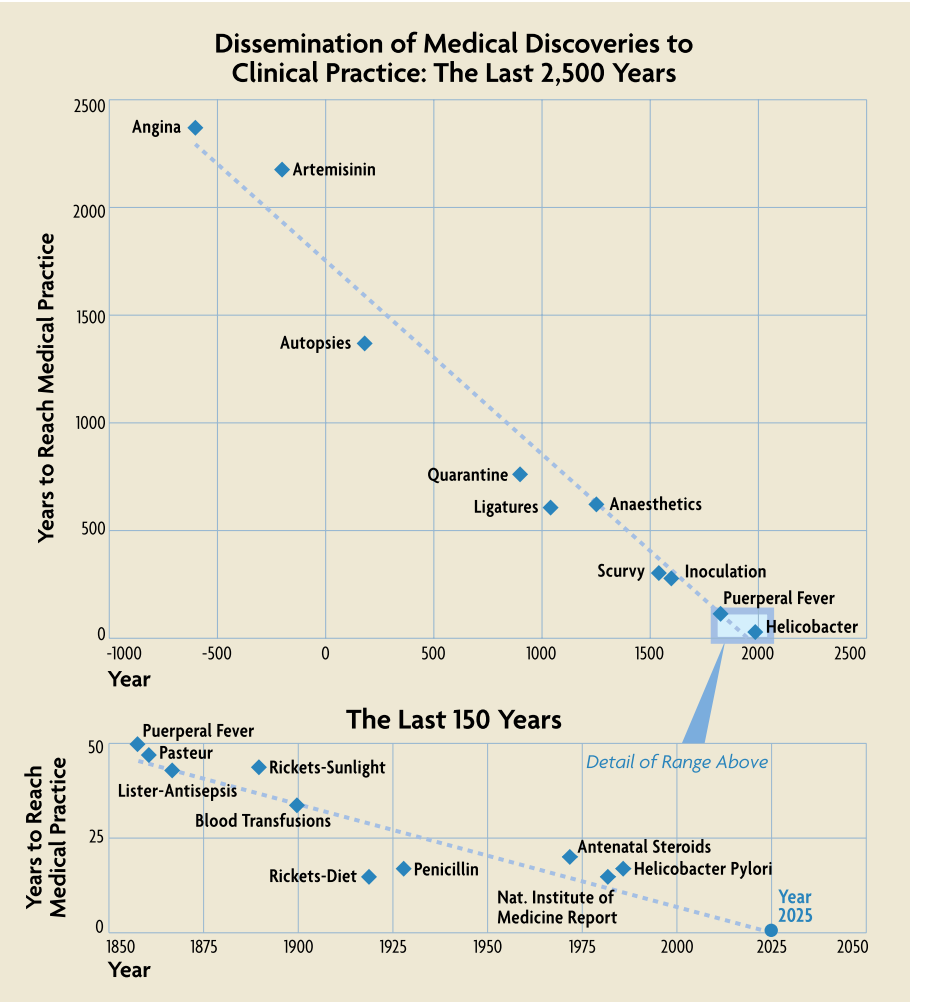

FIGURE 2.

While it took 2,300 years after the first report of angina for the condition to be commonly taught in medical curricula, modern discoveries are being disseminated at an increasingly rapid pace. Focusing on the last 150 years, the trend still appears to be linear, approaching the axis around 2025.

While the ideas around a technological singularity remain controversial,[3] the authors refer to this threshold moment, when medical knowledge becomes "liquid" and its flow from research to practice ("bench to bedside") becomes frictionless and immediate, as the "Healthcare Singularity."

THE PROMISES OF A POST–HEALTHCARE SINGULARITY WORLD

Rofecoxib (Vioxx) was approved as safe and effective by the U.S. Food and Drug Administration (FDA) on May 20, 1999. On September 30, 2004, Merck withdrew it from the market because of concerns about the drug's potential cardiovascular side effects. The FDA estimates that in the 5 years that the drug was on the market, rofecoxib contributed to more than 27,000 heart attacks or sudden cardiac deaths and as many as 140,000 cases of heart disease [11]. Rofecoxib was one of the most widely used medications ever withdrawn; over 80 million people had taken the drug, which was generating US$2.5 billion a year in sales.[4]

Today, it is reasonable to expect that after an FDA announcement of a drug's withdrawal from the market, patients will be informed and clinicians will immediately prescribe alternatives. But current channels of dissemination delay that response. In a post–Healthcare Singularity world, that expectation will be met. To enable instantaneous translation, journal articles will consist of not only words, but also bits. Text will commingle with code, and articles will be considered complete only if they include algorithms.

With this knowledge automation, every new medication will flow through a cascade of post-market studies that are independently created and studied by leading academics across the oceans (effectively "crowdsourcing" quality assurance). Suspicious observations will be flagged in real time, and when certainty is reached, unsafe medications will disappear from clinical prescription systems in a rippling wave across enterprises and clinics. The biomedical information explosion will at last be contained and harnessed.

Other scenarios of knowledge dissemination will be frictionless as well: medical residents can abandon the handbooks they have traditionally carried that list drugs of choice for diseases, opting instead for clinical systems that personalize healthcare and geographically regionalize treatments based on drug sensitivities that are drawn in real time from the local hospital microbiology lab and correlated with the patient's genomic profile.

[3] http://en.wikipedia.org/wiki/Technological_singularity
[4] http://en.wikipedia.org/wiki/Rofecoxib

Knowledge discovery will also be enhanced. Practitioners will have access to high-performance, highly accurate databases of patient records to promote preventive medical care, discover successful treatment patterns [12, 13], and reduce medical errors. Clinicians will be able to generate cause-effect hypotheses, run virtual clinical trials to deliver personalized treatment plans, and simulate interventions that can prevent pandemics.

Looking farther ahead, the instantaneous flow of knowledge from research centers to the front lines of clinical care will speed the treatment and prevention of newly emerging diseases. The moment that research labs have identified the epitopes to target for a new disease outbreak, protein/DNA/RNA/lipid synthesizers placed in every big hospital around the world will receive instructions, remotely transmitted from a central authority, directing the on-site synthesis of vaccines or even directed antibody therapies for rapid administration to patients.

PROGRESS TOWARD THE HEALTHCARE SINGULARITY

Companies such as Microsoft and Google are building new technologies to enable data and knowledge liquidity. Microsoft HealthVault and Google Health are Internet based, secure, and private "consumer data clouds" into which clinical patient data can be pushed from devices and other information systems. Importantly, once the data are in these "patient clouds," they are owned by the patient. Patients themselves determine what data can be redistributed and to whom the data may be released.

A February 2009 study by KLAS reviewed a new class of emerging data aggregation solutions for healthcare. These enterprise data aggregation solutions ("enterprise data clouds") unify data from hundreds or thousands of disparate systems (such as MEDSEEK, Carefx, dbMotion, Medicity, and Microsoft Amalga).[5] These platforms are beginning to serve as conduits for data to fill patient data clouds. A recent example is a link between New York-Presbyterian's hospital-based Amalga aggregation system and its patients' HealthVault service.[6] Through these links, data can flow almost instantaneously from hospitals to patients.

The emergence of consumer data clouds creates new paths by which new medical knowledge can reach patients directly. On April 21, 2009, Mayo Clinic announced the launch of the Mayo Clinic Health Advisory, a privacy- and security-enhanced

[5] www.klasresearch.com/Klas/Site/News/PressReleases/2009/Aggregation.aspx
[6] http://chilmarkresearch.com/2009/04/06/healthvault-ny-presbyterian-closing-the-loop-on-care

online application that offers individualized health guidance and recommendations built with the clinical expertise of Mayo Clinic and using secure and private patient health data from Microsoft HealthVault.[7] Importantly, new medical knowledge and recommendations can be computationally instantiated into the advisory and applied virtually instantaneously to patients worldwide.

New technology is bridging research labs and clinical practice. On April 28, 2009, Microsoft announced the release of Amalga Life Sciences, an extension to the data-aggregation class of products for use by scientists and researchers. Through this release, Microsoft is offering scalable "data aggregation and liquidity" solutions that link three audiences: patients, providers, and researchers. Companies such as Microsoft are building the "pipeline" to allow data and knowledge to flow through a *semantically interoperable* network of patients, providers, and researchers. These types of connectivity efforts hold the promise of effectively instantaneous dissemination of medical knowledge throughout the healthcare system. The Healthcare Singularity could be the gateway event to a new Age of Semantic Medicine.

Instantaneous knowledge translation in medicine is not only immensely important, highly desirable, valuable, and achievable in our lifetimes, but perhaps even inevitable.

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