1 First Trainees: The Golden Anniversary of the Early History of Telemedicine Education at the Massachusetts General Hospital and Harvard (1968–1970)

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Recently, interest in creating curriculum in telemedicine for medical students, and in telehealth for nurses and most other health professionals, has spiked because of the healthcare industry's rapid shift to providing care via telemedicine as a means of infection control due to the Covid-19 pandemic [1, 2]. This commentary describes the initial medical student and resident training in telemedicine at the Massachusetts General Hospital (MGH) a half century ago.

John H. Knowles, MD, a Unique Academic Medicine Leader

John H. Knowles, MD, was an MGH-trained cardiopulmonary internist and the MGH General Director who was a principal architect for the Logan International Airport MGH Medical Station multi-specialty telemedicine program (LIA-MGH-TP). He also touched the lives of both Michael Crichton and Ronald S. Weinstein, MD, two of the initial trainees in LIA-MGH-TP. Crichton was a Harvard Medical School (HMS) fourth year medical student, in 1969, and Weinstein was a third year MGH pathology resident a year earlier, in 1968, when each of them, separately, encountered telemedicine for the first time, unknowingly to become recognized as "pioneers in telemedicine training" a half century later.

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When John H. Knowles had enrolled in Harvard College, in the mid-1940s, he focused his attention on extracurricular campus activities including sports and college theater where he was a Hasty Pudding Club's Theater student performer. Knowles' fun-loving college years in Cambridge, and Scollay Square entertainment in Boston, caught up with him when ten medical schools rejected him for admission [3]. Fortunately for Knowles, and the academic medicine community as well, a curious dean at Washington University in St. Louis, Missouri took a chance on Knowles and admitted him into their freshman class. Knowles rose to the occasion and ended up graduating first in his class. He landed what was then the top prize for a medical student anywhere in the United States, an internship in medicine at the MGH.

When Knowles arrived at the MGH as an intern, in 1951, he was riding high on his widely admired Harvard reputation as a nine-varsity letter, three-sport, Harvard College athlete with a high profile on campus as a Hasty Pudding Club's Theater performer. Everyone knew about his miraculous academic turnaround at a highly ranked medical school in the mid-west. Knowles seemed comfortable with his celebrity status and was accustomed to being in the limelight.

Knowles more than lived up to his advanced billing. In addition to his talents as a physician, and his popularity throughout the MGH organization, he was strongly committed to community outreach. That combination resonated with the MGH power brokers in Boston's financial district and the wealthy MGH trustees. They were looking for a new kind of leader for the MGH, somebody who could help transform their stodgy, but beloved, inward-looking Ivy League-minded institution into an outward-looking community leader in healthcare.

Changes in the US healthcare industry, in the mid-1960s, also favored Knowles's emergence as a national leader. His interest in community outreach became relevant to the US healthcare policy agenda. It is noteworthy that the passage of Medicare and Medicaid legislation in 1965 was a game changer for the US university hospital industry. Nineteenth century-style charity wards were eliminated, with their patients being transferred into revenue-generating beds elsewhere in the hospital. Almost overnight, community engagement became a hot topic as a new potential source of revenue for hospitals. The seeds were sowed for the creation of a new wave of community health centers, in urban areas. Knowles had positioned himself to be a leader in that arena [4–6]. It was in that setting that telemedicine popped up on the radar screen in Boston, with Knowles cheering it on as one of its greatest advocates.

The First MGH Telemedicine Trainees

Historically, Michael Crichton was the first HMS student to take a clinical rotation in the pioneering LIA-MGH-TP, in 1969. He is the only HMS student known to have published a chapter in a book about that medical student experience. His book, *Five Patients. The Hospital Explained*, provides an interesting picture of various aspects of academic medicine at the time multi-specialty telemedicine appeared on the scene in Boston, Massachusetts, in 1968 [7]. With respect to his subsequent career, Crichton ultimately chose not to obtain a medical license, or practice

medicine, but he followed the latest medical research advances throughout his career. Crichton wrote his first best-selling novel, *Andromeda Strain,* as an HMS student. He followed this up with his novel and movie *Jurassic Park*.

The first resident-trainee of LIA-MGH-TP was Ronald S. Weinstein, M.D., a co-author of this article. Weinstein is 81 years old and still works full time as the Founding Director of the national award-winning Arizona Telemedicine Program, in Tucson, Arizona. Weinstein is President Emeritus of the American Telemedicine Association. He is a pathologist who had his fellowship training at the MGH and Harvard in cancer biology research. He spent much of his research career studying cancer cell invasion and metastasis and, later, mechanisms of cancer multi-drug resistance [8, 9]. Weinstein has been recognized as the "father of telepathology," a subspecialty of telemedicine. He invented, patented, and commercialized robotic telepathology and introduced the term "telepathology" into the English language [10, 11].

John H. Knowles, MD, as a Mentor

In 1962, John H. Knowles, MD, at age 35, became the youngest General Director in the history of the 150-year-old MGH [6] (Fig. 1.1). A high-energy individual, Knowles was actively involved in HMS training programs at multiple levels. As MGH Hospital General Director, Knowles personally took ward service call a week each month. Weinstein recalls Knowles participating in the weekly medicine

Fig. 1.1 (Left) Dr. John H. Knowles examining a patient. A highly competitive college athlete, Knowles had been a standout three-sport Harvard varsity letterman, in baseball, hockey, and squash. (Photo credit: Leonard McCombe/The Life Picture Collection/Getty Images). (Right) MGH General Director John Knowles meeting with a group of visitors at the MGH. He was "extraordinarily articulate, elegant in thought, scrupulous and respectful of language" [4]. Knowles was the administrator behind the establishment of the Logan International Airport MGH Medical Station telemedicine program. The MGH Medical Station was an integral component of Knowles MGH community outreach program for Boston. (Photo credit: Leonard McCombe/The Life Picture Collection/Getty Images)

morbidity and mortality (M&M) meetings in the Bulfinch Building. Knowles took pathology residents presenting their autopsy case results through their paces.

Knowles could discuss complicated medical cases on the fly, thinking out loud, using brilliant reasoning, presenting his summaries and conclusions in verbal paragraphs, always with theatrical flair. At the end of each commentary, he would stand with that endearing smile on his face, and methodically nod with raised eyebrows, individually, to each of the tenured Harvard professors in the conference room. In other settings, Knowles strongly encouraged MGH trainees, such as Weinstein, to step up into leadership positions that "would make a difference in the world" [4–6]. A decade later, still at the relatively young age of 45, Knowles was named President of the Rockefeller Foundation in New York City. This provided Knowles with a platform on which to continue his work on US healthcare delivery system reform and community outreach.

Origins Logan International Airport MGH Medical Station Telemedicine Program

On October 4, 1960, an Eastern Air Lines, Lockheed Electra L-188 prop-jet commercial airliner crashed immediately after takeoff from runway 9 the Logan International Airport, in Boston. The airplane struck a flock of starlings at an altitude of approximately 120 feet and crashed into Winthrop Harbor, an extension of Boston harbor. Dozens of passengers were killed. While many on board were killed instantly in the crash, there were also survivors with critical injuries that subsequently died without medical care. Getting emergency medical personnel out to Logan International Airport (LIA) was a logistical nightmare as the only ground transportation access was through the Callahan Tunnel, the single gateway to and from downtown Boston. Telemedicine emerged as a practical solution [12–14]. Knowles was a strong proponent from the start, although the idea for it was not his own. That came from his clinical counterpart, the cardiopulmonary internist, Kenneth T. Bird, MD.

In 1962, the same year Knowles became MGH General Director, Ronald S. Weinstein, a second-year medical student at Tufts Medical School (TMS) across town, accepted a one-year post-Sophomore fellowship in biophysics and electron microscopy in the MGH Department of Neurosurgery, which housed the Mixter Laboratory for Electron Microscopy, headed by Stanley Bullivant, PhD, a pioneer in a new field, freeze-fracture electron microscopy. Three years later, Weinstein was awarded a pathology residency at the MGH, becoming the first TMS graduate accepted into any MGH residency program. Knowles, and the MGH Chair of Neurosurgery, William H. Sweet, MD, encouraged Weinstein to apply for a National Institutes of Health (NIH) grant as a Principal Investigator on a Program Project grant. Knowles personally signed the request letter for an NIH waiver allowing the award [15–17]. Knowles liked Weinstein's career trajectory. He proudly acknowledged Weinstein's accomplishments as a success story for community outreach since Weinstein had been recruited to MGH from Tufts Medical School, across town.

On January 3, 1963, the Logan International Airport MGH Medical Station, a cooperative venture between MGH and the Massachusetts Port Authority, orchestrated by Knowles, opened to patients with Dr. Kenneth T. Bird as its medical director. Within a few years, the clinic was seeing 100 patients a day. The creation of a Logan International Airport telemedicine service was Bird's idea [12]. He was tired of driving back and forth between the MGH and the Logan Airport. Telemedicine stood out as a potential solution, and Knowles provided resources to support the effort. John Knowles saw telemedicine from a larger perspective. For him, it was a success in the development of his MGH community outreach programs. While Knowles would never detract from the originality and importance of Bird's contributions, nor fail to give Bird full credit for his innovations and achievements in LIA-MGH-TP, nevertheless LIA-MGH-TP was recognized as one of Knowles' signature achievements as well [14] (Fig. 1.2). Dr. Bird coined the term "telemedicine" [12].

To create the MGH telemedicine program, LIA was linked to the MGH, 2.7 miles away, over a private bidirectional microwave telecommunication linkage [13]. At that time, NASA (National Aeronautics and Space Administration) was exploring

Fig. 1.2 Telemedicine (initially called "Telediagnosis" at the MGH) was featured in the January 11, 1969, issue of the popular magazine "TV Guide," nine months after the Logan International Airport-MGH Medical Station telediagnosis program became operational, on April 8, 1968. (Left) Cover of January 1969 TV Guide featuring the 65th birthday of the comedian Bob Hope. Hope died at age 100 in 2003. (Right—two-page spread in this issue of TV Guide). (Upper photo) A dermatology patient at the walk-in Logan International Airport MGH Medical Station "Telediagnosis clinic" is being examined remotely by television. (Lower photo) Kenneth T. Bird, MD, at the MGH, is examining the dark irregular purple skin lesion on the patient's left foot, using the robotically controlled-TV camera out at the Logan Airport. The patient's left leg is covered with a light-colored drape (Upper photo). Dr. Bird, looking straight ahead, is viewing the skin lesion on a black-and-white TV monitor. (not shown). He is adjusting the TV image magnification and focus of the patient's foot lesion by manipulating a TV control panel with his right hand. Dr. Bird uses ear buds to listen to heart and breath sounds coming from an electronic stethoscope (not shown)

terrestrial applications for technologies developed to care for astronauts in space [18, 19]. The health of astronauts was constantly in the news. Many doctors and nurses knew what an electronic stethoscope was and believed that it might even outperform the traditional stethoscope. The MGH was following NASA's lead in its implementations of electronic devices for remote patient care. As a frame of reference, the first lunar landing took place just a few months after Crichton graduated from HMS in 1969. The LIA-MGH-TP program was 4 years in the planning [12].

Crichton's and Weinstein's Involvements with Telemedicine as MGH Trainees

Crichton was a fourth year Harvard medical student when he rotated through the Medical Station telemedicine service (initially referred to as a "Tele-diagnostic Service"), in 1969.

In 1968, Weinstein had his first involvement with remote television microscopy. His background in biologic research and medical imaging was unusual for a medical student. He first became involved with high-resolution electron microscopy in 1960, when he was Head Chemist in the Department of Research Services, at the Woods Hole Marine Biology Laboratory (MBL), in Woods Hole, Massachusetts [20]. This was a summer job, between semesters, first at Albany Medical College, in Albany, New York, and then at Tufts Medical School, in Boston, where Weinstein became a transfer student. His assignment as an MGH post-sophomore fellow in electron microscopy was to redesign the equipment used for preparing biological specimens for high-resolution freeze-fracture specimen electron microscopy [21]. The goal was to take the resolution of freeze-fracture electron microscopy down to the molecular level.

Weinstein succeeded well beyond anybody's expectations. Use of his "Type II Freeze-Fracture Device" provided exquisite images of what became known as "connexin complexes" and their hydrophilic channels that are the structural basis for electronic and metabolic coupling between human epithelial cells [16, 17, 22]. He, and a collaborator, N. Scott McNutt, went a step further and showed that deficiencies in these complexes are early manifestations of malignant transformation in certain human cancers [23]. Weinstein's special interests in medical imaging were well known in the MGH Department of Pathology and at Harvard Medical School. This interest led directly to his involvement with the LIA-MGH-TP [15].

In 1967 prior to the opening of the LIA-MGH-TP clinic, a Harvard Medical School Professor and staff pathologist at the MGH, Robert E. Scully, MD, became involved in testing television microscopy equipment to determine its suitability for doing remote clinical microscopy (e.g., light microscopic examination of blood smears and urine sediments using television). Scully kept Weinstein in the loop. (Fig. 1.4) First, Scully examined the need for color television as compared with black-and-white television. He demonstrated nearly 100% diagnostic accuracy using standard black-and-white television [25]. This was not surprising since television microscopy (later called "video microscopy") had been used for biological research starting in 1955. When Weinstein was Head Chemist at the MBL, during

Fig. 1.3 (Left photo) Dr. Weinstein's 2018 visit to the MGH, marking the 50th anniversary of his original participation in television microscopy cases coming in from the Logan International Airport. MGH's White Building's first floor main hallway entrance into the Emergency Ward. The MGH Tele-diagnostic suite was on the first floor, in an alcove off the Emergency Ward. (Right photo) Marking the 50th anniversary of television microscopy in the Pathology Department at the MGH. Dr. David Louis, Castleman Chair of Pathology (left), is with Dr. Weinstein in the MGH Pathology Department Library (April 27, 2018). Dr. Castleman, for whom the Chair is named, is present in Fig. 1.4. (Fig. 1.4, front row). Dr. Robert B. Colvin, a former Castleman Chair of Pathology, is pictured in the oil painting on the wall. In the 1968 MGH Pathology Department annual photo (Fig. 1.4, taken 50 years previously, in 1968), Dr. Colvin was an MGH pathology trainee (Fig. 1.4, last row, second from the left). (Reproduced with permission from [20])

his summer breaks in medical school, he had frequently visited laboratories where video light microscopy experiments were underway and discussed the technology with senior investigators. Based on his survey of the field, Weinstein was able to reassure Dr. Scully that doing routine black-and-white television microscopy as a substitute to traditional hands-on light microscopy worked well and had little risk.

One day in 1968, while Weinstein was signing out surgical pathology cases with Dr. Scully, Dr. Scully invited him to lunch and said the reward would be "something special." Following lunch in the MGH staff cafeteria, they walked over to the telemedicine suite on the first floor of the White Building (Figs. 1.2 and 1.3). Once there, Dr. Scully telephoned the nurse-manager at the MGH Walk-In Clinic at Logan Airport. He reviewed the clinical history of the first patient with Weinstein and then asked the nurse to place the blood smear of Case #1 on the stage of the television light microscope out at the airport. An image of the blood smear popped up on the television monitor in their darkened room. (Fig. 1.5) Dr. Scully instructed the nurse on where to move the slide on the microscope stage, how fast to move it, and where to stop and focus. Several times Scully said "higher" or "lower" to instruct the nurse on bringing the blood sample on the glass slide into optimal focus. After examining a Wright Stain stained blood smear for several minutes, Scully asked Weinstein for

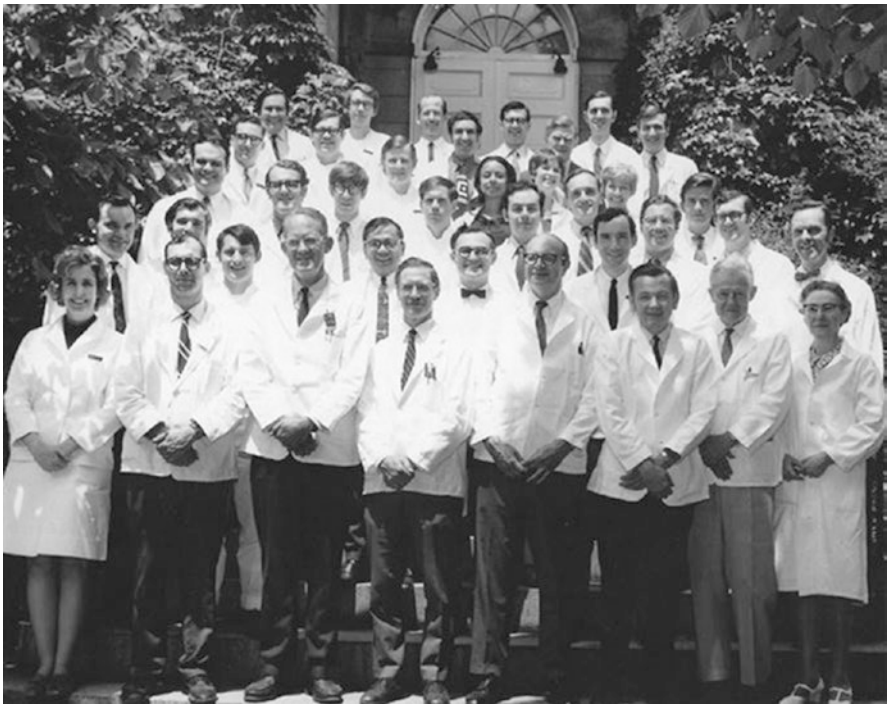

Fig. 1.4 1968 MGH Department of Pathology on the steps of the historic Bulfinch Building, a National Historic Landmark. Robert E. Scully, MD, is in the front row, 3rd from the right. Dr. Weinstein is in the 3rd row, 3rd from the right, standing behind Dr. Scully. Benjamin Castleman, MD, Chair of the MGH Department of Pathology, is in the front row, 4th from the right, standing next to Dr. Scully. Robert B. Colvin, MD, a future Castleman Chair, is in the last row, 2nd from the left. In his long career at the MGH, Dr. Castleman trained 15 future pathology department chairs and produced over 2000 professional publications, a nearly unimaginable number today. (Reproduced with permission from [24])

a diagnosis. Weinstein and Scully agreed on the diagnosis of "hypochromic microcytic anemia" which Scully then reported to the nurse over the telephone. They went through the same routine for Case #2, which turned out to be a "normal" blood smear. Dr. Scully said, "Well, Ronnie, we just made history." They agreed that the process had been straightforward, easy to do, that color television was not required, and the black-and-white television images were surprisingly good.

Crichton's Medical Student Book "*Five Patients. The Hospital Explained*"

Michael Crichton's student involvement with telemedicine education and training was much more extensive than Weinstein's. Crichton's experience was the subject of a chapter in "*Five Patients. The Hospital Explained,*" a book he completed writing just months before his graduation from HMS and published in 1970 [7].

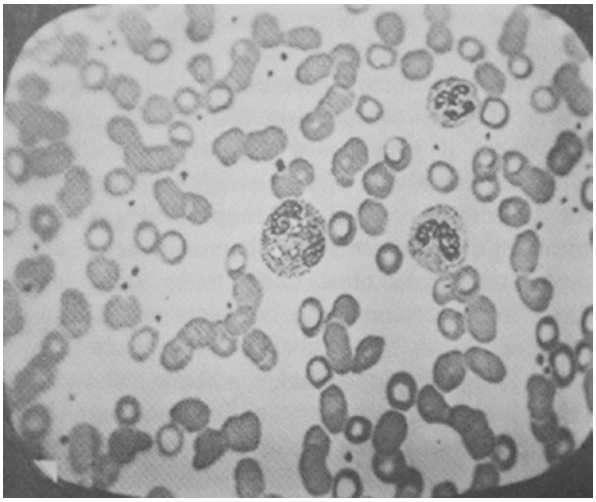

Fig. 1.5 Example of a television microscopy (video microscopy) image of a Wright Stain blood smear, originating at the Logan International Airport MGH Medical Station, and viewed on a black-and-white television screen at the MGH. (Photo credit: Raymond LH, Murphy, JR, "Telediagnosis: A new Community Health Resource: Observations on the Feasibility of Telediagnosis Based on 1000 Patient Transactions." American Journal of Public Health, February 1974; 64(2): 113 to 119, Figure 2, American Public Health Association [26])

While completing "*Five Patients,*" Crichton had discussions with Dr. Knowles about his experiences on the MGH telemedicine service, and their potential implications for healthcare in the future. Knowles' opinions and concerns show up in the text as sage observations by a learned mentor. Knowles also enriched Crichton's telemedicine experience by connecting him with senior MGH staff and with eminent professors at the Massachusetts Institute of Technology (MIT), a virtual temple for research on medical computer applications as well as leading edge research on Artificial Intelligence (AI).

Crichton's book "*Five Patients: The Hospital Explained*" is somewhat of a time capsule of what academic medicine was like a half century ago. On the one hand, Crichton was intrigued by the technologies of healthcare and the complexity of healthcare delivery, but on the other hand, hospital deficiencies were sobering to him, and the ambiguities of medical diagnostics and frustrations of the medical staff over uncertainties that permeate many aspects patient care, even in a world-class hospital, discouraged Crichton from taking the final step into medical practice (Fig. 1.6) . He did not apply for a medical license. Still, Crichton never lost his interest in medical sciences and emerging technologies, and he stayed current with advances in medical research for the rest of his life [27].

The "five patients" in Crichton's book were five actual cases of men and women in immediate need of medical help rushed to the MGH [7]. Crichton uses these cases to explain how hospital practice was changing in the age of science-technology explosion. Crichton used one of his cases to discuss the patient-experience using

Fig. 1.6 Michael Crichton, dressed in surgical scrubs, during a Harvard Medical School (HMS) clinical rotation, in 1968. Crichton, a student of English literature, had a playful sense of humor regarding his own towering height. Here, the 6' 9" Crichton is dressed to recognize Sir Jeffrey Hudson (see surgical cap label), a storied member of the Seventeenth Century court of the English queen Henrietta Maria of France with height challenges. Crichton also wrote a medical mystery, "A Case of Need," for which he received an Edgar Award in 1968, using the pseudonym Jeffery Hudson. He wrote a collection ("The Med School Years Collection") of 8 paperback thrillers in medical school using the pseudonym John Lange. (This Figure is reproduced from http://www.michaelcrichton.com/doctor/, with permission from Taylor Crichton. Ronald S. Weinstein, M.D. was a Teaching Fellow at HMS, while an MGH pathology resident and laboratory director, and taught pathology to Michael Crichton's HMS class)

videoconferencing with a doctor on the other end. He discusses the limitations of the technology, and he considers advances in developing next-generation technologies for patient care, including decision support systems and Artificial Intelligence (AI). Crichton realized that computer programs could offer extraordinary possibilities: any community in the country, "or even a doctor's office could plug into the MGH program and let the computer monitor the patient and direct therapy" [28]. This sounds modern even today.

Crichton's Telemedicine Patient Workup

The telemedicine patient Crichton assisted in working up, as a senior medical student, was Mrs. Sylvia Thompson, a 56-year-old mother of three who began to experience severe, but not persistent chest pain over Ohio on a flight from Los Angeles to Boston. After the plane landed, she was directed to the Logan Airport MGH Medical Station near the Eastern Airlines terminal. After explaining her problem to the secretary, she was led to the telecommunications-equipped clinical examination room (Fig. 1.2). After a brief orientation by the nurse, Dr. Raymond Murphy, at the

MGH, popped up on the TV screen. He had gotten in on the ground floor of this new industry [26]. Off-camera was Michael Crichton watching the proceedings and taking notes [7].

After the Logan Airport Medical Station nurse gave a brief history and her physical findings, blood pressure 120/80, pulse 78, temperature 101.4, Dr. Murphy said, "How do you do, Mrs. Thompson." The nurse told a slightly flustered Mrs. Thompson, "Just talk to him," which she did. Dr. Murphy said, "I'm at the Massachusetts General Hospital. When was your first pain?" He then took a complete history.

This was followed by a physical examination, including a stethoscope examination of the patient's heart and lungs. The airport nurse, following verbal instructions from Dr. Murphy, at the MGH, placed the small electronic stethoscope bell on the patient, while Dr. Murphy listened to the patient's heart and lung sounds live through earbuds. After wheeling the remote controlled "portable" camera over to Mrs. Thompson, Dr. Murphy examined the patients' abdomen and face simultaneously on two separate monitors. The nurse took an ECG and transmitted an image of the ECG paper strip to Dr. Murphy who looked at it on a TV monitor.

While the examination was proceeding, another nurse was preparing samples of Mrs. Thompson's blood and urine in a laboratory down the hall. The nurse placed the samples on glass slides under a microscope attached to a black-and-white RCA TV camera. She and Dr. Murphy could view the images simultaneously as described earlier. The patient had a white count of 18,000.

Back in the examination room, Dr. Murphy said, "Mrs. Thompson, it looks like you have pneumonia. We'd like to have you come into the hospital (MGH) for x-rays and further evaluation." Although the telemedicine-enabled clinic had a television microscope for use for "clinical microscopy" from the beginning, teleradiology was still being evaluated and was not ready for implementation. Afterward, Mrs. Thompson said: "My goodness. It was just like the real thing."

When Mrs. Thompson set off for the MGH miles away, Dr. Murphy discussed her case, and the television link-up with Crichton. Dr. Murphy said, "It's interesting that patients accept it quite well." In retrospect, looking back 50 years, both the patient's perception of the encounter and Dr. Murphy's observations were very instructive. Today, we know that telemedicine is often convenient, efficient, easy to do, and generates a high level of both patient confidence and provider satisfaction. Why was telemedicine not widely adopted a half century ago? The answer turns out to be regulatory inertia, including the legal process that had imposed "deadweight costs" and impeded progress. Another huge barrier was reimbursement. A half century later, the Covid-19 pandemic has served as an innovation accelerator. Following Presidential and Governors' Executive Orders mandating social distancing and stay-at-home orders, and the waiving of burdensome restrictions on payment and urban, home, and nursing home telemedicine in general, telemedicine usage in the United States and the world took off. Tens of thousands of medical practices implemented telemedicine. Telemedicine cases soared 5000–8000%, or more, within months. Characterizations of telemedicine were in line with those of the pioneers. To patients, "It was just like the real thing." Providers were impressed that "patients

accept it quite well." In Microsoft's ads for their Teams" products, the announcer says, "Telemedicine is here to stay."

Telemedicine and the Study of Innovations

While Crichton was on his telemedicine "rotation," he also became interested in the use of computer-based patient history taking. At that time, 15% of patients examined by Telediagnosis had their medical history taken by computer before they saw the tele-physician. Crichton was impressed with the remarkable ease with which patients accepted it. For the interview, the patient sat in front of a tele-type computer that asked questions, and they punched "yes" or "no" responses. "Yes" answers generated more questions. At the end of the interview, the computer produced a medical summary. Unlike the questions, the summary used medical terminology. The process took roughly 30 minutes.

Crichton simulated a computer interview in "*Five Patients.*" He presented the computer with the same presenting complaint as that of Mrs. Thompson: chest pain. He then attempted to confuse it by feeding suggestive information, namely a family history of coronary artery disease and that the patient was taking digitalis. In later questions, the machine was fed a straightforward history for the type of chest pain most common in medical students—that of pain of psychogenic, or musculoskeletal, origin. At the conclusion, the computer printed out a summary.

Crichton noted that the computer program drew no conclusions about diagnosis; it only summarized answers to its own questions, and it did not cross-check itself. He also noted that there were more sophisticated programs available at the time and expands on the research taking place in the MGH Computer Science Laboratory [7]. Dr. Jerome Grossman said, "computers in the future will help with a doctor's critical decision, if a patient needs to see the doctor at all." In 1969, Grossman predicted that, "In the near future, when the home computer and the television set is practical, you're going to be able to plug right into the hospital computer without even leaving your home." It turns out that it took decades to have electronic health records with patient portals enabling patients' immediate access to their own records. Kathleen Dwyer, in Dr. G. Octo Barnett's Laboratory of Computer Science at the MGH, noted "there's no theoretical reason why you couldn't build a program to carry out some of the functions of a doctor…." In other words, the roles of physicians as diagnosticians may be endangered, but not eliminated completely [28].

In *Five Patients*, Crichton then discusses the broader implications of what he had observed on his two-week rotation and, in doing so, reveals his own remarkable level of sophistication in thinking about innovation and technology. There are echoes of John Knowles' voice in this conversation. First, Crichton acknowledges that it is the role of university medical centers to lead in the development of technology, and then disseminate it out into the community. He foresees that hospital physicians may some day direct the diagnosis and therapy of patients who never enter the hospital. In his day, neither television nor computers had much impact on hospital practices. They do today, in many parts of the hospital.

We are beginning to see the early fragmentation of the late twentieth-century and early twenty-first-century "big box" hospitals with the physical diffusion of some component parts out into the community. An example might be the loss of hospitals, and free-standing imaging centers, of their near monopolies of large diagnostic imaging equipment. For example, in a growing number of metropolitan areas, computed tomography (CT) scanners are being taken to patients' homes in specialized vans equipped for remote diagnosis by tele-physicians located at virtual hospitals or in HIPAA-compliant home offices. Nearly a dozen metropolitan areas in the United States already offer such direct-to-patient tele-stroke services. A prospective patient dials "911" and describes physical findings suggestive of an impending stroke. The message goes to a call center that dispatches a van, equipped with an on-board CT scanner, directly to the patient's home. The patient is placed in the head scanner. A medic performs the CT scan, which is transmitted, typically via cellular data networks, directly to an on-call tele-vascular neurologist or neuroradiologist. CT images are immediately interpreted, and a vascular tele-neurologist carries out the complimentary physical examination via telemedicine, often rendering the diagnosis from the display on a smartphone. A diagnosis of ischemic stroke results in the immediate intravascular infusion of tPA, the "clot busting" drug, averting a potentially life-threatening stroke. "Door-to-needle" times have been reduced to under 30 minutes for thousands of impending stroke cases. Barrow Neurological Institute, in Phoenix, Arizona, offers this service 24/7 [29].

What Will Harvard Medical School Teach Students in Their Telemedicine Courses?

Recently, HMS proudly announced they are introducing telemedicine into curriculum at multiple points. That is good news for the telemedicine industry, but not necessarily good for traditional medical practices (i.e., pre-Covid-19) [1, 30].

Harvard Medical School's adoption of a telemedicine-centric curriculum was done on-the-fly, apparently with an "all hands-on deck" sense of urgency [1]. Of course, this is best viewed through the lens of Covid-19 pandemic. The Covid-19 pandemic has caused a sea change in the healthcare industry, affecting far more than telemedicine. Many medical practices have gone "virtual" in a matter of a few months. Anecdotal evidence indicates that the transformation from in-person office appointments to "virtual" visits has taken place at previously unimaginable rates. Earlier predictions of 36 million telemedicine cases for 2020 before the Covid-19 pandemic set in are now being increased to 1 billion or more telemedicine cases by the end of 2020 [31]. Adding telephony (telephone only cases) and text-messaging into the equation, these numbers become staggeringly large going forward.

The good news is that the transition from traditional bricks-and-mortar practices to virtual practices seemed reasonably straight forward. The rise of high-speed broadband Internet communications over the past 25 years, the widespread adoption of mobile smartphones by businesses and consumers, the availability of rapidly scalable cloud computing infrastructure and services, and, most recently, the

accessibility of secure and reliable synchronous video communications and asynchronous messaging, all laid the groundwork necessary for the recent explosive growth in implementation and utilization of telemedicine by healthcare providers and the patients they serve throughout the United States and the world.

The Association of American Medical Colleges (AAMC), the leading voice for medical education in the United States, has recognized the importance of including telemedicine in medical school curriculum of US medical schools. What will the core competencies be? Are there lessons to be learned from earlier efforts to teach a telemedicine curriculum? What is missing in this conversation? [2, 30, 31].

It is likely that both Crichton and Weinstein would express their concerns over a loss of the in-person humanity, empathy, and caring in the current Zoom-based world, even though Crichton chose not to practice medicine and Weinstein became a pathologist, a field with minimal direct patient contact. Even they knew that body language matters, and environment affects behavior. Although they went separate ways following their training, Weinstein into cancer research and academic department leadership, and Crichton into full-time writing and movie directing, each valued their professional relationships, their interpersonal interactions, and even their patient interactions in medical school. It could be that Zooming would not have been either of their preferred choices for people-to-people communication.

As Eric Topol, MD, a leading thinker in the Artificial Intelligence arena, and an outstanding practicing physician, has noted, "All of these humanistic interactions are difficult to digitize, which further highlight why doctors are irreplaceable by machines." He wisely concludes, "Machine medicine need not be our future" [32]. However, healthcare technologies do belong in the modern doctor's bag. Physicians will want to include telemedicine and other healthcare technologies as instruments in their medical tool kit, which they can utilize as needed to aid in the diagnosis and care of patients [33].

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