Introduction

EVANGELISTS AND MARTYRS

Though sometimes portrayed as merely serendipitous, the discovery of new sources of ionizing radiation in 1895 and 1896 was actually the predictable result of ongoing research into cathode rays and other electrical phenomena made possible by increasingly powerful electrical equipment and new developments in vacuum tube technology. The application of radiation for therapeutic ends also represented a natural progression; individuals working with radiation could not help but notice that it affected their bodies, causing burns and other physiological results. The observation of results, however, did not imply understanding. The intermingled triumph and disaster of early radiation therapy turns on a simple fact: people figured out that X-ray and radium treatment *did* work, in the sense of visibly reducing tumors or infections, long before they understood *how* it worked. To understand *why* X-ray exposure could burn skin or cause hair to fall out would require a new understanding of matter, energy, and human bodies. As a result, early radiation therapy operated on a kind of faith, tapping into an unseen and mysterious power to deliver miracles of healing.

Early adopters took on the role of evangelists, spreading the good word about the miracles of X-rays and radium, fighting back against skeptics and competitors, and battling with one another over the "true" interpretation of radiological omens and portents. Eventually they would end up as martyrs, consumed along with numerous patient sacrifices in what one X-ray therapist called the "Baal-fires" of ionizing radiation. No character exemplifies the dynamics of this narrative better than Heber Robarts, the founder of the *American X-Ray Journal* and the first president of the American Roentgen Ray Society. Robarts always made an impression. He was one of the first Americans to experiment with using X-ray technology in medicine, and a vigorous popularizer and advocate for the use of radium in cancer treatment. Robarts lived a life by turns glorious and ignominious. He was a bombastic self-promoter and a thin-skinned editor with little tolerance for disagreement. Colleagues variously venerated him as a founder and denigrated him as a quack; the flavor of his reputation at any particular moment reflected some of the larger conflicts that divided practitioners of radiation therapy. Robarts's experience with X-rays and radium also reflected the larger conundrum of the field, insofar as it killed him. Indeed, Robarts began to work with radium in the hopes that it would treat his X-ray-induced cancer. That choice throws into stark relief a question that recurs throughout this study: why did patients and practitioners accept the risks of radiation exposure in the face of clear evidence of its danger?

The first would-be radiation therapists needed faith because they operated in a space of uncertainty: uncertainty about the technology and how it worked, uncertainty about the causes of disease, uncertainty about the professional structure of medicine, uncertainty about the availability of materials, and even the day-to-day uncertainty of running a small business. Unfortunately, that faith proved too durable; radiation therapists failed to respect the dangers of radiation exposure even in the face of clear evidence of harm. Faith in the technology and hope for future breakthroughs made radiation workers too comfortable with uncertainty, and people got hurt as a result.

Radiation therapy is necessarily a topic with a broad scope. In addition to featuring two very different technologies—X-ray emitters and radium sources—the historical narrative of radiation therapy encompasses a large and diverse group of people. Although some early radiation therapists were doctors with medical degrees, many of the early practitioners were inventors, pharmacists, medical students, or entrepreneurs, as the relative lack of regulation in the late nineteenth and early twentieth centuries meant that people with incomplete or no medical education could open clinics devoted to X-ray therapy or sell tonics containing radium. Together, this group of early adopters—the radiation evangelists—developed therapeutic procedures through a process of trial and error, often on patients, that raises important ethical questions not only for historians but for the contemporary practice of medicine.

X-ray and radium technologies received a burst of scholarly attention beginning in 1995, with Joel D. Howell's *Technology in the Hospital*.[1] This book expands that conversation specifically around the early development of radiation therapy, examining the development of radium and X-ray therapy in the thirty years following Wilhelm Conrad Röntgen's 1895 discovery of X-rays.[2] I consider both of the major technologies deployed as therapeutic tools in the early twentieth century, and I attempt to elucidate not just what therapists were doing but how they thought about radiation, risk, and the therapeutic process. As a case study, the radiation therapy narrative opens a window into the process by which new technologies get transformed into therapeutic tools. That no one understood precisely how radiation worked, or how it would affect human bodies, makes this story exemplary rather than extraordinary. Whether attempting to build neuromechanical interfaces for replacement limbs or trying to use genetic manipulation for therapeutic purposes, today's physicians and medical researchers still live with uncertainty and still face many of the same temptations and risks confronted by the radiological faithful.

Movement without Progress

For physicists and chemists working with X-ray emitters and radium, the two decades that followed the discoveries of Röntgen and Henri Becquerel proved enormously exciting and productive.[3] In some ways, radiation and radioactivity represented a challenge to basic ideas about the world. Radioactivity, for example, fundamentally refuted the notion of atoms as indivisible and unchanging and made real the old alchemical dream of transmutation. In biology the story proved more complicated. For biologists, X-rays and radioactivity would push some researchers in fruitful new directions, especially with respect to their attempt to understand the origins of life. But the phenomena would also become fodder for the latest instantiation of anti-Darwinism, breathing new life into movements that attempted to describe the study of life in exclusively supernatural terms. Biologists had some sense that the energy output of radiation had interesting effects, but they did not yet have a paradigm for understanding those effects, although Hugo de Vries would posit the eventual way forward—radiation as mutagen, and therefore as a source of cellular damage—as early as 1904.[4]

For medical users, the experimental application of radiation to human bodies only exacerbated the problems created by their lack of a biological paradigm, and the process of knowledge creation seemed almost to go in the wrong direction: as users accrued more experience with X-ray emitters and radioactive substances, they often seemed to know less—a sort of movement without progress. The results of radiation exposure differ greatly when observed across different kinds of tissues, cells, and organisms, in part because the types of radiation generated by particular sources can differ substantially in their characteristics and effects. Moreover, it soon became clear that radiation exposure can have long-lasting effects, even after the initial symptoms fade. For practitioners experimenting with radiation therapy the basic questions of their field remained unanswered from year to year, even as new uncertainties and variables proliferated in a seemingly endless train. On April 18, 1901, at a meeting of the Roentgen Society of London, radiotherapist Margaret Sharpe summed it up thus:

> In November, 1899, I first had the honor of addressing you on the subject of x-ray therapeutics. At that time we were indebted for most of our knowledge of the subject to the labors and writings of our colleagues on the Continent, and our own practical experience was of the smallest. Now things are very different: x-ray departments have sprung up at many of our large hospitals, both general and special, and a few of our skin specialists have introduced the treatment in their consulting-rooms. Cases we have had in plenty . . . but are we still open to the reproach, so abhorrent to the British medical mind, of dealing with an unknown, or, at best, a but little understood force? Are we agreed as to the nature of the force, or the nature of its action, or as to whether it is simple or complex, one or many? . . . I myself have lately arrived at some very definite conclusions on most of these points; how long they will hold out I don't know, perhaps not after tonight.[5]

Of course, physicists, chemists, and biologists also faced frustrations and new problems raised by work in the area of radiation. For medical users, however, the huge gaps in their understanding of the relationship between radiation and living systems created particularly pressing problems. Therapists worked with radiation not in an effort to understand how the world works but rather in an effort to treat sick patients. Therapeutic users needed to understand ionizing radiation in a way that would allow them to predict its effect on a particular disease, suggest the most effective methodologies for particular circumstances, and make possible the maximum benefit while minimizing the risk of further injury to the patient.

But five years passed, and then ten, and still the key fact of radiation therapy remained: no one knew precisely why, or how, it worked.

The responses of radiation therapists to this uncertainty ran the gamut. Some practitioners attempted to address the problem through measurement and quantification. Many developed intricate theories to explain the results and phenomena that they had observed while working with X-rays or radium. Some therapists flatly denied elements of the problem, claiming, for example, that X-rays did not actually cause harm to patients. Many ignored elements of the problem, like the fluctuating air pressure of their emitters, often for reasons of cost or difficulty. For therapists worried about the possibility of exposing their patients to unknown risks, one of the most common responses to uncertainty was for the therapist to expose him- or herself to the treatment—a kind of gentleman's agreement to excuse risk so long as it was equally endured by both parties. Practitioners also tried to push back against uncertainty in the same fashion as their colleagues in other disciplines: by actively sharing knowledge through mechanisms like societies, conferences, and journal publications.

Radiation Therapy as Case Study

Uncertainty in treatment is an unavoidable problem in medicine. Human bodies are ferociously complex, responsive systems whose functioning relies on mechanisms at every level from the macroscopic and mechanical, such as tendons anchoring muscles to bones and air moving through passageways into the lungs, to the atomic, where mitochondria harvest energy for cellular activity by shifting electrons and protons in the citric acid cycle. It naturally follows that influences at any level of the biological apparatus can lead to unpredicted changes, and problems, in other parts of the system. As a result, new therapies almost always imply a degree of uncertainty and risk—a fact repeatedly demonstrated by the recall of new drugs or changes in the recommendations made by professional medical organizations.[6] These problems were not new in 1896. At the November 1, 1900, meeting of the Röntgen Society, society president John Macintyre pointed out that if therapists could not live with such uncertainties, "we might despair of a complete scientific basis for much therapeutic research. Take any sample drug we are in the habit of administering. How much do we know of how it acts? We know it largely by its results, but whether taken into the alimentary canal or injected into the circulation, it must act in some subtle, but often unknown way" in the body.[7]

This core uncertainty at the heart of medical practice is what makes a study of radiation therapy both interesting and useful. The response of users to uncertainty in X-ray therapy suggests useful questions to ask both about other historical episodes, like the deployment of dialysis machines and of retroviral drugs, and about current and future therapeutic technologies that promise major breakthroughs for previously untreatable diseases, but where the mechanisms of action and the possible consequences or side effects remain poorly understood. Several other elements make radiation therapy a particularly useful site for historical inquiry. Both its timing and the professional record that developed around radiation therapy make this a particularly interesting moment in the history of medicine and technology. Radiation therapy persists into the present, in some ways relatively unchanged, and its use as an anticancer agent, both then and now, dramatically sharpens the ethical questions faced by therapists. Moreover, the risks and problems associated with radiation therapy can be mitigated with better technology, but they cannot be "solved"; X-ray therapists and cancer patients today still contend with some of the same uncertainties that users faced a century ago.

Of course, the value of this case study is also determined by its accessibility. Fortunately, the people involved in that story left behind a rich historical record. The rise of radiation therapy coincided with the rise of the professional press in medicine, and radiation therapists published widely both in general circulation journals, like the *Journal of the American Medical Association* and the *Lancet*, and in specialist publications, like the *American X-Ray Journal* and the *Archives of the Roentgen Ray*. Public interest in X-rays and radium meant that these technologies also received wide coverage in the popular press, and reporters found no shortage of radiation therapists willing to give interviews or offer quotes. The development of this new field also led to a flood of books—textbooks and technical monographs, but also memoirs and philosophical treatises—and a sea of pamphlets, brochures, and other advertising materials from companies eager to sell vacuum tubes, film, and radium water to any physician looking to expand into radiological practice. Early therapists also left behind personal accounts, records, journals, and pictures.

Many of the people involved in the development of radiation therapy explicitly wrote or preserved materials with an eye toward history. Therapists like Robarts and Émil Grubbé saw themselves as the vanguard of a shift that would change the medical world, and they wanted to make sure that their own contributions received the proper recognition and appreciation. The written record is also deep, however, because X-ray and radiation therapy developed at a moment of enormous conflict and change in the medical community, and those conflicts provided ample fodder for discussion and debate in the pages of the medical press.

Discovering New Sources of Radiation

On August 22, 1879, William Crookes addressed the British Association for the Advancement of Science. Crookes opened his lecture with a brief nod to the work of Michael Faraday. Faraday, in 1816, hypothesized that matter could exist in a fourth state, "as far beyond vaporization as that is above fluidity." Faraday coined the term *radiant matter* to describe this state; modern physicists call it plasma.[8] Faraday lacked the technological means to test his hypothesis, but he set the path that would eventually lead to the discovery of X-rays. Heinrich Geissler, a German glassblower and eventually, physicist, would take the next step, making it technically possible to produce Faraday's "radiant matter." Geissler began his professional life as a traveling artisan. A master glassblower, Geissler found a steady clientele in Germany's universities by specializing in the creation of blown-glass apparatus for experimental research. Eventually his name would become synonymous with vacuum tubes: the term *Geissler tube* refers to a sealed glass tube, evacuated by a pump to a low internal air pressure, with an electrode at each end, allowing for an electric current to pass through the tube. Neon and mercury-vapor lights are modern forms of the Geissler tube.[9]

Numerous nineteenth-century experimenters, including Crookes, worked with vacuum tubes, and many produced new iterations of the technology. In a basic Geissler tube, the application of a current produces light (its color determined by the composition of gases in the tube) in the space between the positive and negative electrodes. A small zone of darkness, however, surrounds the negative pole, or cathode.[10] By using new, more powerful pumps, Crookes dramatically increased the degree of vacuum in his tubes, and he noted that the size of the dark space around the cathode would increase in tandem with the falling pressure inside the glass envelope. Eventually the dark space filled the vacuum tube, and the glass wall opposite the cathode began to glow with an eerie luminescence, its color determined by the material used to produce the bulb—English glass glowed blue, uranium glass dark green, and German glass (the most commonly used substance) phosphoresced in a shade of "bright apple green." Crookes described his findings in a series of lectures and publications on radiant matter. He correctly deduced that the dark space represented the mean free distance that a particle leaving the cathode could travel before striking another particle; in high-vacuum tubes, the charged particles traversed the full-length of the tube without encountering any other obstacle and struck the glass, causing the phosphorescent effect.[11] Physicists would eventually identify these "cathode rays"—so named for their point of origin—as streams of electrons.[12]

Crookes publicized his work widely, and other experimenters rushed to replicate his results and investigate this new phenomenon, replacing their Geissler tubes with new "Crookes tubes" capable of achieving higher levels of internal vacuum and producing cathode rays. The "Crookes tube" moniker stuck, becoming the default designation for the whole class of energized vacuum tubes, despite the efforts of other innovators to further alter the apparatus and promote their own noms de tube. One such experimenter, Philipp Lenard, succeeded in replacing a portion of the vacuum tube's glass wall with a piece of aluminum foil. Lenard found that this arrangement allowed some of the cathode rays to escape the Crookes tube; he could detect the wayward rays by means of a cardboard screen treated with fluorescent paste, which glowed when placed in front of the aluminum window. Since the glass walls of the apparatus would also phosphoresce, Lenard covered his tube to prevent it from outshining the fluorescent screen. Lenard published his results in October of 1895.

The Discovery of X-Rays

Röntgen, then head of the physics department at the University of Würzburg, decided to replicate Lenard's experimental setup, including the fluorescent screen and the covered tube. When he initially energized the covered tube, however, Röntgen noticed that the screen, still lying on a chair a few feet away, immediately began to fluoresce. Röntgen expected the screen to fluoresce only when he put it close to the emitter; Lenard's experiments had shown that cathode rays could travel only a short distance—about eight centimeters—in regular air. Röntgen's screen glowed at a distance of two meters.[13]

The magnitude of that difference suggested to Röntgen that the fluorescence resulted not from cathode rays but from some heretofore unknown force. In the footnotes of his first paper on the subject, Röntgen wrote, "For brevity's sake I shall use the expression 'rays'; and to distinguish them from others of this name I shall call them 'x-rays.'" Following up on his suspicion that these "x-rays" differed from cathode rays, Röntgen began a series of experiments. Over the subsequent seven weeks, the physicist spent almost every waking hour working with X-rays. The Röntgen family lived in an apartment over the lab, and an oft-repeated legend holds that Anna Röntgen made possible her husband's obsessive hours of observation by slipping quietly in and out with hot meals. Through various experiments, Röntgen found that "all bodies are transparent to this agent, though in very different degrees," as determined primarily by density (although he noted that other, as yet unexplained factors also seemed to play a role in the degree of transparency). X-rays did not deflect in the presence of a magnet; Röntgen regarded this as the acid test distinguishing the new emanation from the cathode rays previously studied by Lenard and others. Eventually, Röntgen concluded that cathode rays *produced* X-rays when they struck either the glass wall of a normal Crookes tube or Lenard's aluminum window.[14]

Röntgen also tested his X-rays with photographic plates. Because unabsorbed rays expose photographic plates and film, X-ray photographs come out as "shadow pictures," based on the differential absorption of the materials in the photograph. Denser substances, like bone, produce less-exposed negative spaces, while lower-density materials, like soft tissues, look ghostly or invisible on the resulting photo. The most famous of Röntgen's pictures shows the bones of his wife's hand, her wedding ring visible as a dark blob over the fourth finger. Röntgen, like many subsequent X-ray users, found that "the production of [shadow photographs] has a particular charm," noting in his initial report that, in addition to photos of hand bones, "I possess, for instance, photographs of the shadow of the profile of a door which separates the rooms . . . ; the shadow of a covered wire wrapped on a wooden spool; of a set of weights enclosed in a box; of a galvanometer . . . ; of a piece of metal whose lack of homogeneity becomes noticeable by means of the x-rays, etc."[15] In December, Röntgen finally took a break from his work to write up the results and send them off, along with the photo of Anna's hand, to the *Sitzungsberichte der Würzburger Physikalischen-Medicinischen Gesellschaft*—the house journal of the Physico-Medical Society of Würzburg—which published the report on December 28, 1895.[16]

Fortuitous circumstances brought Röntgen's discovery to the public with unusual speed. The editor of the Würzburg *Sitzungsberichte* sent copies of Röntgen's unusual photographs, along with copies of the report, to Franz Exner, a professor of physics in Vienna, who brought them out at a dinner party. One of the guests was E. Lecher, a physicist from Prague whose father was the editor of Vienna's leading daily, *Die Presse*. Lecher passed along the story, and *Die Presse* published the first public account of the discovery on the front page of its Sunday edition on January 5, 1896, although they mistakenly attributed it to Professor "Routgen," a misnomer carried into many subsequent accounts. Britain's *Daily Chronicle* and Germany's *Die Frankfurter Zeitung* both picked up the story, as did the *New York Sun* and the *Saint Louis Post-Dispatch*.[17] The first account of the new technology in the *New York Tribune* appeared in a short paragraph as part of the world news roundup; it described a "light, by which a man can be photographed without flesh or muscle, but as he is in his bare bones." The *Times* ran its first full story on the discovery four days later, under the headline "Hidden Solids Revealed: Prof. Routgen's Experiments with Crookes's Vacuum Tube," and it gives the reader some sense of the immense excitement generated by the discovery, with descriptions of American "men of science . . . awaiting with the utmost impatience the arrival of European technical journals, which will give them the full particulars of Prof. Routgen's great discovery" and his methods.[18]

Becquerel, the Curies, and Radium

In 1896 French physicist Henri Becquerel found that uranium salts, like X-ray emitters, produced "rays" that could pass through low-density substances and darken a photographic plate. Though weaker than an X-ray emitter, uranium emitted energy spontaneously, on a continuous basis. In 1897 Marie Skłodowska Curie decided to follow up on Becquerel's "uranic rays." Curie was uniquely positioned for this research, owing to the groundbreaking work of her husband, Pierre, and his brother, Jacques, on the piezoelectric effect. By combining a precision piezoelectric instrument with an electrometer, the brothers created a system for measuring very small electrostatic effects with a great deal of precision.[19] With such apparatus ready to hand, Marie could accurately measure the energy output of various compounds containing uranium. One such material, uranium pitchblende, emitted significantly higher levels of energy than could be accounted for by the ore's known uranium content. Hypothesizing that the ore must contain trace quantities of other, as yet unknown elements, Marie and Pierre began attempting to isolate the source of that extra energy.[20]

It was a grueling process. Radium is a decay (or "daughter") product in the chain that begins, in nature, with uranium; radium, in turn, decays to form radon gas. The most common isotope of radium, ^{226}Ra, has a half-life—the period in which half of the radium atoms in any particular sample will decay—of 1,601 years. Because its half-life amounts to little more than a blip in geological time, radium does not naturally accumulate in large quantities. Instead, it appears in trace amounts—a fraction of a gram per ton—in uranium-bearing ores like the Curies' pitchblende. To separate radium from the pitchblende required a long chain of chemical treatments, starting with repeatedly boiling and washing the ore, using concentrated soda and acid preparations, and ending with a painstaking process of fractional crystallization that allowed the Curies to gradually produce salts containing ever-higher concentrations of radium chloride. The Curies identified both polonium and radium in 1898, but it took them until March of 1902 to isolate and purify enough radium chloride, one-tenth of a gram, to have its existence confirmed by the calculation of its atomic weight with a spectroscope. The Curies also coined a term, *radioactive*, to describe elements that spontaneously produced radiation.[21]

Much of the initial interest in the new element explicitly focused on using it as an alternative to X-ray emitters. Stories with headlines like "Radium Better Than the X Rays," promised that radium emanations, possessing "all the qualities of the Röntgen rays," meant that "the wonderful results of the x-rays . . . can be duplicated by a method much cheaper."[22] When the Curies began to release small samples of radium and polonium salts to other researchers—an act of generosity that also created additional publicity for their discoveries—the vials emitted a faint, luminescent glow that never failed to excite a crowd. A story in the *Boston Globe* captured the amazement created by this new "light without heat"; according to the reporter, when a scientist at the Smithsonian opened a radium sample, "the room was filled with a clear, greenish glow, bringing out in relief the features of everybody present. The light was cold and harmless, and the substance could be picked up with impunity."[23]

All of the press, along with the more than thirty papers published by the Curies between 1898 and 1902, made Marie and Pierre into scientific celebrities. The couple shared the 1903 Nobel Prize in physics with Henri Becquerel, and Marie became the first person to win the prize a second time, in chemistry, in 1911. The iconic image of radium, used in publications, pamphlets, and advertisements around the world, would show Marie in her blue dress, holding aloft a glowing tube.

Early Radiation Therapy in Context

To show how patients and practitioners understood radiation therapy, this book includes historical analyses based on metaphor and cognition. In the early days of X-ray therapy medical practitioners discussing and thinking about ionizing radiation had to contend with the fact that X-rays are invisible to the naked eye. Moreover, to repeat an earlier point, no one knew precisely how radiation worked in the body. As a result, discussions of radiation therapy inevitably turned into exercises in metaphorical thinking. To give one example, X-ray emitters and vials of radium salts were often visually depicted as miniature suns, with their output of ionizing radiation depicted as the sun's rays. The sun imagery, however, did not simply describe a way of thinking about rays emanating from a source; it also described a possible treatment mechanism. The basic theory held that radiation, in passing through human tissues, could confer the known antibacterial effects of sunlight to places that sunlight could not normally reach, such as the interior of the lungs.

This example illustrates an idea described by George Lakoff and Mark Johnson in their book, *Metaphors We Live By*. Metaphors, according to Lakoff and Johnson, do more than to simply describe a concept through comparison; because humans' "conceptual system is metaphorically structured and defined," a powerful metaphor actually alters humans' perception of the world.[24] Some of the metaphors used to conceptualize radiation would prove useful, as when X-ray therapists realized that an X-ray emitter, like a light source, could be filtered to exclude undesirable bandwidths. But other metaphors would prove problematic. Thousands of consumers drank Radithor, radium-laced water, on the theory that a shot of liquid "energy" could reinvigorate a tired body.

As advertisements from the period make clear, consumers' interest in radioactive health products, like Radithor, reflected an interest in "energy," broadly defined, rather than an understanding of how radiation exposure might affect health. The radium tonic had enormous sales until one of its high-profile endorsers, steel magnate and socialite Eben Byers, suffered a gruesome death when the radium in his body caused his bones to disintegrate.[25] The fate that befell Byers and other Radithor drinkers was unfortunate, but it was also ludicrous—a totally foreseeable tragedy more or less perfectly predicted by the fate, a few years earlier, of the so-called Radium Girls, who suffered similar consequences as a result of licking brushes tipped with radium paint.[26] It is also a reminder that radiation therapy, for both good and ill, cannot be understood solely as the product of decisions made by doctors.

Radiation therapy is interesting as a historical topic in part because of the quirk of its particular historical context: the technology spread amid, and became entangled in, both professional and geopolitical conflicts. On the geopolitical side, the major world powers were, by 1895, actively jostling and maneuvering for strategic advantage in the period sometimes described as the "New Imperialism" that included the Scramble for Africa, the Spanish-American and Russo-Japanese Wars, and the German naval buildup under Kaiser Wilhelm II. On the professional side, a variety of internecine battles were resetting the landscape of medicine in fundamental ways. Taken together, geopolitical and professional conflict influenced the development of X-ray and radium therapy in profound ways.

By 1900 X-ray emitters had already been tested by army doctors in places like Sudan and Afghanistan, and enthusiastic military support would prove extremely valuable to promoters of X-ray technology. Interestingly, the record suggests that prewar international tensions did not shut down or inhibit the professional networks that allowed information to flow back and forth between the German-, French-, and English-speaking radiological communities, but it did lead to a certain amount of posturing, including the eventual decision of British and American X-ray users to do away with the "Roentgen" terminology in favor of words derived from "radiation." Prewar strategic posturing also had a major impact on the physical availability of radium, as countries moved to control and restrict supplies of both radium-bearing ore and refined radium salts. Government investments in radium materials and X-ray emitters during World War I also played an important role in the postwar development of radiation therapy and radium-based consumer health products.

On the professional side, the nineteenth century was a period of intense conflict and transition for doctors and medical researchers on both sides of the Atlantic. Conflict over the ethics of medicine, who could be a doctor, what philosophies of medicine would predominate in the twentieth century, and how medical schools and professional organizations should function set medical professionals against one another. For ordinary practitioners—doctors, but also pharmacists, midwives, surgeons, and a plethora of service providers operating under the nebulous label "therapist"—a debate raged over the interlocking problems of medical theory and professional identity. Members of the orthodox medical community faced challenges to older understandings of disease both from within and beyond their ranks, and successful campaigns to reduce the regulatory barriers to entry in medicine meant that more and more types of practitioners could compete in the medical marketplace. By 1895 the ascendance of germ theory and the revolution in medical schooling and licensure that would come to a head with the Flexnerian revolution were under way but incomplete. A new orthodoxy was taking hold in medicine, and the radiation evangelists would have to situate themselves within it.

As with geopolitical conflict, professional conflict and the changing structure of medicine affected the development of radiation therapy in complicated ways. Initially, many orthodox physicians regarded X-ray technology with skepticism (especially when the new practice threatened to take business), and many continued to regard X-ray therapists as possible quacks or charlatans even after seeing evidence that radiation could treat disease. The professionalism debate also led to divisions within the X-ray community, putting practitioners with degrees and formal medical licenses at odds with noncredentialed X-ray users. But advocates of radiation therapy also benefited from some of the changes taking place in the field of medicine; in particular, X-ray therapists found new ethical standards and the changing role of hospitals in the medical system helpful to their cause.

In nineteenth-century medicine, orthodoxy was essentially defined by consensus. In theory, physicians as a group had settled or would settle on "best" practices (or, at the very least, reject the worst ones). Orthodox doctors specifically described themselves in opposition to "quacks"—practitioners who based their practice on unsafe or unsound theories and principles. For therapists interested in treating disease with X-rays or radium, this dynamic meant that their adoption of a new technology must coincide with a period of consensus-building, convincing colleagues that radiation should count as an orthodox treatment, rather than as quackery. That necessity helps to explain the striking degree of self-promotion that a reader encounters in the early literature on radiation therapy, especially from X-ray therapists: such boasting represented a bid by radiation therapists to be included in the existing medical orthodoxy, rather than expelled from it.

Tradition-based orthodoxy faced a severe challenge in the nineteenth century as new discoveries in biology and chemistry, such as the germ theory of disease, seemed to overturn or supplant some of the most cherished ideas in medicine.[27] New forms of medical research also challenged the old orthodoxy. The growth of large urban hospitals in places like London and Paris and the adoption of new statistical and observational methodologies enabled clinicians to compile data about human biometric norms, the symptoms and progression of specific diseases, and even the comparative value of different treatment regimens.[28] With regard to treatment, the results of these new forms of inquiry were often dismaying; many of the traditional remedies used by doctors showed little or no efficacy under the new forms of analysis, leading, famously, to Oliver Wendell Holmes's exclamation in 1860 that "if the whole materia medica, *as now used*, could be sunk to the bottom of the sea, it would be all the better for mankind, and all the worse for the fishes."[29]

For adherents of new, radiation-based therapies, the rapid winnowing of the medical arsenal that took place in the nineteenth century created an opportunity to make their case as legitimate, orthodox medical professionals. Although ionizing radiation had a wide variety of possible uses, advocates and members of the public alike consistently focused their attention on the use of radiation in previously "untreatable" diseases, especially skin infections and cancers. In fact, this particular case highlights the degree to which concerns of legitimacy might trump the concerns of the medical marketplace. Hair removal was one of the most lucrative and popular early uses of X-ray emitters, yet it received relatively little attention in newspaper accounts and journal articles touting the benefits of X-ray therapy. Advocates of X-ray therapy showed noticeably more interest in promoting themselves as medical professionals treating disease than in advertising themselves as specialists in cosmetic procedures.

Given the degree to which scientific discovery and new research challenged and conflicted with the old medical traditions, nineteenth-century orthodox physicians faced a serious legitimacy challenge. They responded by embracing a specific vision of change: a progress narrative, with medical practitioners as members of a professionalized, scientific discipline that promised, in Warner's words, to make "active efforts to advance medical knowledge and practice" and "readily alter its practices if such change would bring about better care."[30] In reality, of course, a space existed between the *possibility* of change and its actual embrace. Nevertheless, the progress narrative offered a way forward for new types of practitioners, including radiation therapists, to legitimize both new forms of treatment and their own status as orthodox medical professionals.

The redefinition of doctors as scientific professionals runs along slightly different paths in the United States and the United Kingdom, but the basic endpoint—an emphasis on particular types of medical education as the prerequisite for a state-approved license—holds in both contexts. The professionalization progress narrative in medicine thus celebrates licensure as an essential feature of a "modern" or "scientific" system of medicine. In his study of medical licensure, sociologist Jeffrey Lionel Berlant found that orthodox medical professionals promoted it as "necessary to protect the public from medical practice by unskilled and untrained persons." Of course, in return for such protections, those same professionals argued that they should benefit from legal privileges; as suggested by the title of Berlant's book, *Profession and Monopoly*, licensure could easily serve as a way for orthodox physicians to exclude competitors from the medical marketplace. For radiation therapists, the question became whether they would be included among the orthodox insiders, and thus share in the market benefits of professionalization, or excluded and shunned as unprofessional, nonphysician hucksters and quacks.[31]

For both British and American radiation therapists, and especially for X-ray therapists, the issue of licensure and medical education would create significant tensions, both within the community, between degreed and nondegreed practitioners, and beyond it, between radiation therapists and traditional physicians. The barrier to entry for X-ray practice was relatively low; the equipment, though expensive, was widely available, and "treatment," in its most basic iteration, simply required the placement of a subject in physical proximity to an energized emitter. As a result, many "therapists" entered practice without having completed a formal medical education—some without having completed any medical education at all. In seeking to build their legitimacy on the possession of specialized technical knowledge, rather than a medical degree, X-ray therapists without an orthodox medical education were explicitly challenging the licensure status quo.

Radiation therapists were also putting themselves in the middle of a long-running fight over the very legitimacy of medical specialization, which had a long and often checkered history.[32] In the United States and Great Britain specialization only really began to gain traction at the end of the nineteenth century; the discovery of X-rays, in 1895, and the subsequent introduction of X-ray and radium therapy took place at precisely the moment when advocates and opponents of specialization were locked in bitter struggle.[33] The conflict over specialization put radiation therapists in a strange position. On the one hand, X-ray therapists, in particular, explicitly described themselves in a way that seemed to fit with the "specialist" paradigm, deriving their legitimacy from the specialized technical knowledge required to construct and operate X-ray emitters. When applied to the treatment of patients, however, actual radiation therapy looked very different from other forms of specialist practice, both in justification and in fact. Insofar as they accepted the logic of specialization, orthodox physicians in both the United Kingdom and the United States saw the division through explicitly biological terms: specialists could focus on particular body parts or systems—for example, "ear, nose, and throat" doctor—or on particular manifestations of disease. Radiation therapists, by contrast, focused on a particular technology. For a physician working with radium, a tuberculosis infection of the skin and cervical cancer had the same solution, even though the two cases involved different diseases, in different organs, located in different parts of the body. In this sense, radiation therapists looked more like general practitioners than specialists.

Two useful professional models did exist for radiation therapists. Electrotherapy offered a clear example of a medical specialty based on equipment and technical skill rather than medical knowledge. A significant overlap existed between electrotherapy and radiation therapy in the early days, in part because many X-ray therapists started out as electrotherapists. But the practice of radiation therapy dramatically diverged from electrotherapy over time, both because manufacturers simplified X-ray apparatus and because the orthodox medical community increasingly came to regard most forms of electrotherapy as ineffective at best, and quackery at worst—precisely the sort of outcome that advocates of radiation therapy sought to avoid.

The second professional model for radiation therapy came from apothecaries, the pharmaceutical branch of medicine. In many ways, pharmacists served the same role as many radiation therapists, applying a specific set of technical skills and technologies (in this case, chemistry) to heal patients. In the case of radium, in particular, pharmacists sometimes even dispensed a sort of radiation therapy, in the form of over-the-counter tonics and medical devices containing radioactive material. For radiation therapists, however, this professional model did not appeal. Radiation therapists explicitly sought to be received into the medical profession as *doctors*, rather than as technicians or some other kind of professional.

The specialization and professionalization questions, in both Great Britain and the United States, were partly questions of medical ethics, and the upheaval taking place in medicine throughout the nineteenth century extended to the sphere of ethics. Modern readers often think about medical ethics solely in terms of what a modern observer might call "bioethics"—the rules and principles governing the behavior of medical professionals toward their patients. Nineteenth-century "medical ethics," however, focused as much on the elements of professional behavior and relations between physicians as on the physician-patient relationship. As radiation therapists attempted to navigate the ethical challenges of their novel and experimental treatments, the ethical debates over professional behavior would initially loom largest. In the early years of radiation therapy, American physicians regarded fee splitting—the proper division of patient revenues between primary and consulting physicians—as an ethical issue on par with the proper protocols for conducting patient trials with a novel medical technology. To put it more succinctly, in 1898 the issue of pay for a consulting physician offering X-ray cancer treatment could easily be as or more ethically contentious than the question of whether or not that physician should use the same emitter for an experimental body hair removal treatment.[34]

The focus on intraprofessional matters did not mean that American and British physicians had no interest in the question of doctor-patient ethics. Rather, the lack of controversy reflected a general consensus on the basic tenets of doctor-patient relations. That consensus began with two concepts: the virtuousness of the physician's character and intent, assumed to be the foundation of a proper physician-patient relationship, and the ethic of reciprocity, often referred to as the "Golden Rule," which would serve as both a personal rule of measure and a line of defense against patient complaints. Together, these concepts emphasized that ethical behavior was the product of good character, rather than good codes. Ethical decision-making fundamentally lay in the personal judgment of the physician, rather than in the application of pre-existing professional rules or philosophical precepts. The preamble of the American Medical Association's 1903 "Principles of Medical Ethics" expressly declares it to be "a suggestive and advisory document" containing neither rules nor penalties.[35]

Historian and bioethicist Robert Baker describes this ethical framework as "laissez-faire ethical libertarianism," and this approach predominated among X-ray and radium therapists on both sides of the Atlantic. Advocates of laissez-faire argued that ethical behavior resulted from more general principles of society, and that if a physician behaved unethically toward patients, the problem lay not in a lack of formal rules but rather in the flawed character of the individual (which no rules could correct). In particular, advocates of laissez-faire ethics often cited the "Golden Rule"—do unto others as you would have them do unto you—as a universal concept that would produce ethical behavior. In reference to medical experimentation, British medical ethicist Michael Ryan laid out the classic Golden Rule formulation in 1831, writing that there should be no difference in what "the practitioner does or advises to be done, for the good of his patient, and what he would do in his own case, or in the case of those dearest to him." Ryan had no illusion about the dangers of medical experimentation, noting that such experiments had led to fatalities. Nevertheless, he argued that so long as physicians accepted "the most dangerous experiments upon themselves," therapeutic experiments performed under the auspices of the Golden Rule are "not blamable, for they are necessary" in the pursuit of better treatments.[36]

Both X-ray and radium therapists embraced the Golden Rule approach to ethics. In some cases, that ethical choice was very explicit and premeditated—Robert Abbe and Truman Abbe, for example, attempted to treat patients with radium only after testing the samples on their own bodies and carefully observing the results. Intentionality, however, was not actually a necessity. In the early years, most X-ray emitters lacked even the most basic shielding. As a result, even therapists who did not set out to use themselves as guinea pigs still ended up as de facto subjects in a test of the long-term effects of ionizing radiation on the human body. As the dire consequences of that exposure became increasingly clear over the years, the radiation evangelists adopted the religious language of "martyrdom" to describe death by radiation-induced cancer.

The Radiation Evangelists

The aforementioned Émil Grubbé and Heber Robarts, along with Sydney Rowland and a few other early evangelists, are at the heart of the narrative told in chapters 1 and 2, which focus on the five years from January of 1896, when news of Röntgen's discovery broke, to December of 1900, when the American Roentgen Ray Society held its first annual meeting. An incredible flurry of activity took place during this period—what I call the "Röntgen rush"—and chapter 1 chronicles the efforts of the first would-be X-ray therapists to set up clinics and experiment with the new technology. Chapter 2 follows the evangelists in their attempts to create technical organizations, specialist journals, and the other scaffolding of a medical profession in a community where not everyone agreed on what it meant to be a doctor.

Chapter 3 follows Robarts and Grubbé through the internecine battles for professional legitimacy that permanently embittered both men. By examining the struggles for control of the *American X-Ray Journal* and its associated professional organization, the chapter puts a human face to the forces of professionalization and medical specialization. The radiation evangelists had to contend with technical difficulties and therapeutic uncertainty, but as happens in any church, they also had to work through power struggles and ego-driven squabbles. For Robarts, bitterness over the outcome would ultimately lead him to reject X-ray therapy and turn to radium.

Chapter 4 turns back to the technology itself, taking a deep dive into the devices used by early X-ray therapists to power their equipment and produce X-rays. Stanley Joel Reiser describes medical technologies as having "two essential dimensions: form and purpose."[37] We often think of form as driven by purpose; for example, "What form of vacuum tube will best achieve my purpose of generating X-rays?" In reality, however, the two dimensions exist in a reciprocal relationship. X-ray therapy offers an example of the reverse case; only after they observed the effects of X-rays on their own bodies did X-ray users turn the existing emitter form to a new, therapeutic purpose. Cold cathode emitters, radium seeds, emanators, and radium salts were physical things in the world, and the specific properties of their forms played a crucial role in determining the development of radiation therapy. In the case of X-ray emitters, the particular properties of the devices, and especially the difficulty of controlling variables in the emitters' operation, would hamper the efficacy of treatment and make it much more dangerous for patients, even as the relative availability of parts and ease of operation made it possible for individuals without medical degrees to offer X-ray "treatment."[38]

Chapters 5 examines the development of X-ray therapy leading up to the First World War; it considers the perceptions of users, with an eye toward the problems created by the space between users' understanding and the realities of the equipment. Together, the chapters argue that this disconnect, when combined with the seemingly endless optimism of X-ray enthusiasts, ultimately led to tragedy, in part because users covered over their uncertainty with faith, rather than treating uncertainty as a problem in need of an immediate solution.

Chapters 6 and 7 follow that turn, shifting the focus of the narrative away from X-rays and over to radium, the other tool of early radiation therapy. Chapter 6 uses the records of two physicians, Robert and Truman Abbe, to sketch out both the dynamics of the early radium industry and the process of experimenting with radium treatments. Radium samples, in sharp contrast to X-ray emitters, were produced by mining and refining large quantities of radioactive ore, and the initial scarcity of the substance would dramatically affect both access to radium therapy and its public perception. Chapter 7 devotes attention to the dynamics of this market, which became the subject of considerable political and commercial competition in the years prior to World War I. The chapter also considers the process by which radium eventually became a consumer health product rather than a specialized treatment.

For both patients and practitioners, the fundamental appeal of radiation therapy seems to have arisen from the association of ionizing radiation with light, and especially with sunlight. From the earliest newspaper headlines of 1896 to the prewar covers of the *Archives of the Roentgen Ray* and the *American X-Ray Journal* to the 1920s-era pages of Radithor sales brochures, the images and descriptions of ionizing radiation consistently depict both X-rays and radium in this fashion. Everyone knew that the energy of the sun—its warmth and its light—lay at the very foundation of life on Earth. It therefore makes a certain kind of sense that people trusted these new energy sources. We also use the warmth of the sun as a metaphor or shorthand for optimism: a sunny outlook or a sunny disposition or a new day dawning. This connection, too, suits the radiation therapy narrative particularly well, given that advocates of radiation therapy were nothing if not optimistic and enthusiastic.

This light, however, did not drive back the darkness; it created uncertainty, rather than dispelling it. At the end of his life, Heber Robarts's optimism was not borne out: the radium Robarts managed to obtain did not cure his X-ray-induced cancer. Likewise, this study is not the glorious history that he hoped it would be—the tale of radium and X-ray pioneers conquering all human suffering. And yet Robarts was also right. Radiation *can* cure cancer, or at least treat it, and radiation therapy *has* improved countless lives in the century since Robarts succumbed to the effects of his own exposure. This, then, is not so much a tale of failure as an examination of the tangled thicket of contradictions and complications within which technological medical progress so often happens. The history of radiation therapy offers a useful reminder that success is often only the endpoint of an otherwise cautionary tale.