Early Innovations and Explorations in Radium Therapy

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Abstract— **The discovery of radiation and radioactivity at the dawn of the 20th century led to an explosion of scientific activity. X-rays discovered by Roentgen quickly became instrumental in medical diagnosis and treatment, and nearly in parallel, radioactive radium salts discovered by Pierre and Marie Curie became one of the most expensive and sought-after materials worldwide. Through historical publications, reprinted scientific addresses, and textbooks from the era, this work explores early clinical practice in the pre-nuclear age, including a selection of applicators and devices that illustrate the inventiveness and creativity of that era.**

Keywords— **Historical texts, Radium, Brachytherapy, Medical Devices**

I. Introduction

As the therapeutic modality brachytherapy approaches a quasquicentennial of clinical use, it is appropriate to mark the achievements and discoveries of the pioneering practitioners whose adventures and discoveries paved the way to modern medical practice. This work comprises a selective review of published literature from the pre-nuclear era, *i.e.*, prior to 1945, to summarize notable examples of early and innovative medical practice utilizing brachytherapy. In order to limit the breadth of this topic, this review deliberately excludes use of radium baths, elixirs, or external beam treatments treated via radium-bombs.

II. Medical practice

Biological effects attributed to radiation exposure were observed from the very pioneer who discovered radioactivity. H. Becquerel experienced a skin burn in April 1901 after carrying radium for six hours in his shirt pocket [1]. This exposure caused an erythema that transformed into moist desquamation and ultimately left a depigmented scar. P. Curie experienced a similar reaction following a 10-hour exposure from radium powder intentionally placed on his forearm. However, the first *published* description – in a 1900 German photography journal - was made by F. Walkoff, who described 'a skin inflammation that has now persisted for two weeks, exhibiting exactly the same symptoms that appear after long-term X-ray exposure' [2].

These early demonstrations of superficial biological changes likely led to early clinical use of radium by H. Danlos, a dermatologist working in Paris, who treated a patient with lupus on their face using radium chloride (see Figure 1). [**Error! Reference source not found.**]

Fig. 1: Photo of H Danlos treating lupus using radium [**Error! Reference source not found.**]

In the 1905 textbook *Radium and Radio-Active Substances, Their Application Especially to Medicine* (~ 160 pages), C. Baskerville – a Professor of Chemistry at The City College of New York – described many reports of skin ulceration caused by exposure to radium, including self-exposures by Walkoff, Becquerel, Curie, and others [3]. Baskerville also summarized radium-mediated experiments on guinea pigs, rabbits, larvae, meal worms, mice, milk, bacteria (B-coli, B-diphtheriae, bacillus typhus, etc.), and plants, among others examinations. It is notable that this very early text – appearing within years of the discovery of radium – encapsulated a myriad of reported therapeutic interventions, some of which are listed below using the spelling and phrasing present in the original text.

- Lupus, including hypertrophicus and vulgaris
- Epithelioma
- Telangiectesis
- Cancers / carcinoma & malignant disease
- Rodent ulcers (*i.e.*, type of basal cell carcinoma)
- Eczema
- Psoriasis
- Acne
- Moles
- Cyclitis and irido cyclitis (*i.e.*, forms of uveitis or ocular inflammation)
- Hair removal

In many of the indications above, Baskerville included comparison to equivalent studies utilizing X-rays and discussed observations of the different effects of X-ray, γ-ray, and β-ray radiations. As a summary of this impressive 'Catalog of Ships' (*i.e.*, detailed listing of studies and published references), Baskerville stated, "It is too soon to draw any conclusions from much that has been done. It is unwise to make any final statements. However, we know this much: that the radium rays possess the power of dilating the vessels; that they have an electric action; also, an influence upon the cells of quickly growing tissues and possible bactericidal properties. These three factors give bright promise of its therapeutic use, when we shall have learned more about this wonderful substance" [3].

The landmark clinical guide *Radiumthérapie*, originally written in French, was published by dermatologist L. Wickham and physician P. Degrais in 1909. [4] A second edition followed only three years later [5]. Translated versions were readily produced, including an English translation by S. Ernest Dore that featured a preface by Wickham and incorporated additions and updates to the original French version, namely the "development of radiumtherapy as applied to malignant tumors, and the unquestionable value of the method devised by us for the treatment of most forms of vascular nævi" [6]. The tome is divided into three parts: physics (~15 pages), use of instruments (~50 pages, see also Section 0), and clinical therapeutics (> 200 pages). The treatment concept of 'cross-fire' is introduced as "a bombardment of the tissues by rays emitted from different points at the same time, and therefore crossing each other" [6]. The definition is demonstrated by a clinical case of an infant successfully treated in 1907 for a "reddish-violet erectile tumour" by Wickham where the radium appliances were moved externally to prevent erythema to the skin while focusing the applicators at depth in tissue.

The sections describing therapeutic results were grouped into sections as follows, using the language and phrasing of the original text.

- Carcinomata and other malignant growths
- Cheloids and disfiguring scars
- Angiomata
- Pigmentary nævi
- Tuberculosis of skin and mucus membranes
- Analgesic action of radium
- Pruritus, neuro-dermatitis, eczemas;
- Various diseases (e.g., mostly case studies)
- Gynæcology

Each section was essentially a collection of case studies, and the authors concluded each section with a summary statement or concluding remarks.

Other texts from this era had similar breadth and scope to Wickham and Degrais's work. These included *Radium Therapeutics* (~110 pages), a 1913 publication by dermatologist N. S. Finzi [7] and *Radium and Radiotherapy; Radium, Thorium, and Other Radio-Active Elements in Medicine and Surgery* (~310 pages) by W. S. Newcomet, a professor of Roentgenology and Radiology [8]. Of interest, Newcomet incorporated a final chapter titled "Treatment of Untoward Effects of Radio-Active Elements" that described potential acute or chronic sequelae of exposure to radionuclides, often comparing effects to those obtained via Roentgen-rays. Newcomet stated, "If the person withdraws from his vocation and ceases to handle these radio-active elements the condition rapidly subsides, and in a few weeks or months he may return to duty..." [8].

In a 1913 speech at the Seventeenth International Congress of Medicine in London, R. Abbe, a New York surgeon, spoke about his experience using radium sources, including a 150 mg radium-barium chloride source obtained directly from Madame Curie in 1903 [9]. Referencing past successes using radium to remove common warts, Abbe successfully used radium to treat large vocal cord papilloma for multiple patients, including some that failed prior surgery. In this address, Abbe mentioned the practice of 'radiosurgery' where surgery was employed to de-bulk a tumor attached to the carotid artery, with radium subsequently applied to treat residual tumor and prevent recurrence; however, the use of the term 'radiosurgery' as a course of surgery with adjunct brachytherapy did not persist.

Abbe shared promising results for several patients with advanced cervical cancer and is often credited as a pioneer of radium-based gynecological therapy in the United States [10]; although, the electrotherapeutist M. Cleaves published her experience treating cervical cancer with sources loaned from C. Baskerville in 1903 [11]. In a similar vein, Abbe is frequently associated with pioneering the technique of afterloading, namely placing a hollow applicator into a tumor and later loading sources into the applicator to reduce dose to the physician during temporary treatments; however, that distinction more appropriately belongs to H. Strebel working in Munich. [12] These nuanced attributions should not detract from the pioneering and inspirational role played by Abbe as a champion for the medical use of radium in the United States [10].

The use of radium to treat brain tumors was reported in 1922 by H. K. Pancoast and included contributions from C. H. Frazier at University Hospital dating back to 1914 [13]. Radium treatments were conducted either by afterloading sources into the resection cavity or by cross-fire radiation externally applied through the scalp. The risks attendant to these procedures included the general risk of surgery, infection risks related to placing and removing radium sources, healing of the surgical flap following external radiation, and radiation doses to normal brain.

The Chicago-based dermatologist F. E. Simpson published the textbook *Radium Therapy* in 1922 (~320 pages) [14]. Approximately half of the text featured a physical, chemical, and biological discussion of radium and radium emanations, including a detailed description of a radium emanations generation plant and several depth-dose

measurements of radium dose using ion chambers. For treatment applicators, Simpson described radium tubes, radium needles, and "flat plates, or plaques, on which the radium salt is spread" that were generally constructed using linen (known as "toiles"), rubber, or metal. Radium emanations were primarily captured in capillary glass tubes 3 to 20 mm in length with outer diameter of 0.3 to 0.6 mm. For external use, Simpson recommended an "ingenious method" based on a secondary encapsulation of the glass tube within a silver tube (16 mm length, 3 mm diameter, and 0.5 mm wall thickness), as described by G. Failla.

The chapters on treatment were grouped by medical practice:

- Surgery,
- Gynecology,
- Dermatology,
- Ophthalmology (including rhinology and laryngology),
- Diseases of the ductless glands, and
- Internal medicine.

The final chapter was titled "professional injuries due to radium" and described potential local and constitutional effects for radiation workers. The final recommendation in the text was "it is imperative that radium workers should abstain from work for at least two days per week and should have frequent vacations of one or more months' duration."

A 1926 book by A. E. Hayward Pinch on practice and technique in radium therapy further provided insight into the growing appreciation of radiation safety two decades into the clinical use of radioactive material [15]. The text stated that frequent handling of sources "will sooner or later induce definite inflammatory and trophic changes in the fingers and hands of … workers." Recommendations stressed that "All apparatus should be handled with wooden or rubber covered metal forceps, at least a foot in length, and the hands should be protected with leather gloves." The publication featured a large number of photographic plates that illustrated the state of brachytherapy practice a century ago (e.g., see Figure 2).

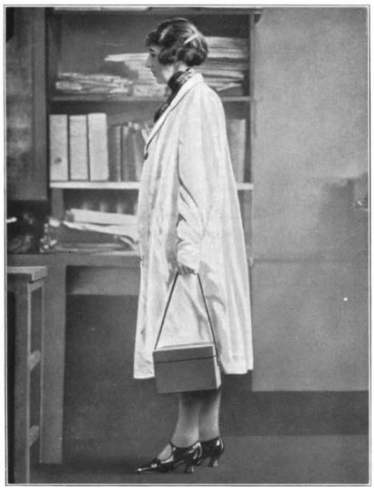

Fig. 2: An attendant carrying radium in a shielded container [15]

Hayward Pinch's text was focused on equipment and technique and included only a brief discussion of clinical methods. Sources were applied in three different ways: direct insertion of sources into superficial tumors; use of "trocar, canula, and plunger" as an afterloading technique; or, the introduction of seeds. A subsequent chapter was dedicated to special situations, specifically, the nose, mouth & tongue, pharynx and fauces, larynx, esophagus, stomach, rectum, uterus, bladder, prostate (via the urethra, perineum, bladder, or rectum), and (female) urethra. It provided a high-level summary of the general technical approach in these anatomic locations, but did not discuss prescriptive practices. Additionally, a chapter listed the most common complications and sequelae arising from treatment, with headings summarized as follows.

- Bacterial infection
- Telangiectasia
- Pigmentation
- Ulceration
- Annular fibrosis (commonly in the vagina & rectum)
- Burns (due to accident, negligence or ignorance)

Hayward Pinch distinguished between expected sequelae of desquamation and ulceration from inappropriate use of radium resulting in more serious soft-tissue damage.

G. E. Birkett authored a 1931 textbook based on the technique employed at the Manchester and District Radium Institute [16]. This text featured six color plates, reflecting printing advances in the early part of the 20th century. The second chapter was titled "Protection" and stated the risks to radiation workers. Birkett provided examples of three workers, where two developed aplastic anemia and the third experienced myeloid leukemia. Formal recommendations of the x-ray and radium protection committee are reproduced in this text. To further emphasize care in the use of radium, the fourth chapter was titled "Radium Burns." The discussion differentiated between burns caused by β rays and those caused by γ rays, with the former largely prevented by using appropriate source filtration and the latter resulting in more serious morbidity. Birkett further described 'immediate burns' that presented 2-3 months after beginning treatment and 'delayed radiation necrosis' that arose potentially years after treatment.

The remainder of Birkett's text was devoted to clinical practice. Birkett stated, "The indiscriminate use of radium on the off chance of something happening has never appealed to us, and there should be good grounds for its use in each and every case" [16]. This mindset parallels the 'evidence-based medicine' approach that formally dawned at the close of the 20th century. Birkett included the following carcinoma-related uses: rodent ulcer, bladder, buccal cavity, anal canal, cervix uteri, rectum, skin, and vagina / vulva. A handful of other examples are listed (e.g., Hodgkin's disease in the parotid, lympho-sarcoma, and mediastinal tumors, among

others); however, Birkett repeatedly warned "against the indiscriminate use of radium."

While radium use for carcinoma was well documented, some researchers pursued applications in benign disease. An example of this was illustrated by a 1934 publication by Phaneuf who treated 150 patients for small fibromyomas, menorrhagia (*i.e.*, heavy menstrual bleeding), and metrorrhagia (i.e., abnormal uterine bleeding unrelated to menstruation) in uteri [17]. Phaneuf achieved good results using a small amount of radium and minimal apparatus; however, this is one example of medical practice that did not become standard of care.

Prior to the dawn of the nuclear age, New York physician D. Quick provided an overview of the current medical use of radium at a 1940 address to the Conference on Applied Nuclear Physics (Cambridge, MA) that was later published in 1942 [18]. While acknowledging that radium was also used in inflammatory and hyperplastic conditions, the focus of the address was cancer therapy. Quick acknowledged that during the same period, significant advances in the technology and equipment used for Roentgen ray therapy had occurred. There was enthusiasm by many to focus on the rapidly advancing Roentgen ray technology, and Quick stated that "Some of the [roentgen therapists] had little opportunity to study radium concurrently, and many have not taken the time."

He reviewed the three primary treatment processes for radium use: external / surface, intracavitary, and interstitial. While Quick noted that a small skin growth responded better to a "larger amount of radium at 1 cm distance," much of the surface treatment discussion compared Roentgen rays to teleCurie therapy. For intracavitary treatments, Quick noted the "outstanding results" reported for cervix uteri treatment. For other sites, he commented that "in the entire gastrointestinal tract radium is of negligible value until the lower sigmoid and rectum are reached." He discussed the potential benefit of evaluating dose and fractionation, stating "My experience with intra-uterine irradiation has been much more favorable with smaller amounts over several days rather than larger amounts for twenty-four to thirty-six hours." Finally, Quick reviewed the interstitial uses of radium and radon, with a focus on irradiation accompanying surgical procedures. He said, "It may salvage an operative procedure which would otherwise have been a failure through inability to carry out a complete removal, or the operative procedure may have been solely for the purpose of permitting proper localization of the needles or implants." He listed a number of sites that could benefit from this adjunct method as follows:

- Epidermoid carcinoma of mouth & pharynx
- Cervical Metastases
- Axilla in breast cancer
- Primary breast cancer (some)
- Bladder
- Prostate
- Cervix uteri carcinomas (some)
- Inguinal metastases of external genitalia carcinoma
- 'Various other growths'

On this topic, Quick enthusiastically added, "it is my firm conviction that practically no surgical procedure on a growth of questionable operability should be undertaken, in all fairness to the patient, without a proper supply of radium, in some suitable form, available to aid in the possible salvage of a difficult situation" [18].

In summary, Quick reviewed the "close and complementary relationship between surgery, roentgen rays, and radium." He reviewed how filtration had reduced the rate of necrosis, but also admitted that the very good past results obtained from unfiltered sources warranted additional study. He also commented on the intravenous use of aqueous compounds, the growing interest in radiosensitizers, and the potential for new radioactive compounds. It was unlikely that he appreciated the coming nuclear age and the availability of new radionuclides.

III. Instruments and applicators

The first decades incorporating radioactive material in medicine produced a wide variety of techniques and applications. In the very early years, radium was primarily available in the form of mineral salts that could be infused into applicators and molds. Even encapsulated sources were produced in different forms using various materials, which challenged standardization. However, clinicians designed and implemented a number of tools to achieve therapeutic goals. This section explores notable examples from the pre-nuclear era.

C. Baskerville in his 1905 textbook included a short discussion of equipment used in therapeutic treatments that highlighted the heterogeneity of devices at the dawn of medical use [3]. Patient-facing materials included rubber (for "higher activity"), quartz, mica, silver, glass, lead, and others, demonstrating the often physician-specific customization of applicators. Figure 3 shows a variety of surface applicators produced by Philadelphia manufacturer Williams, Brown & Earle.

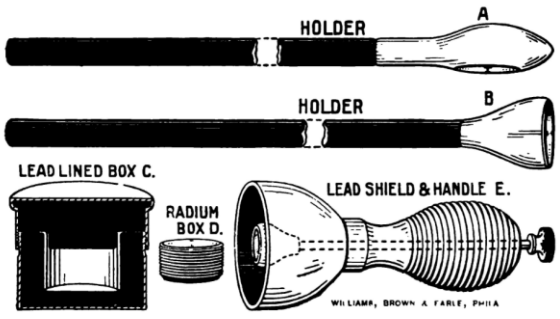

Fig. 3: Surface radium applicators for applying radium compounds [3]

Radiumtherapie includes a robust description of equipment available only five years later. Wickham and

Degrais spend little time on the use of radium in the form of tubes, which were generally radium salts sealed in glass with the option to be inserted into a second tube of gold, silver, or platinum of variable thickness to obtain a desired radiation intensity [4-6]. Instead, they described a family of devices created by using varnish to seal radium salts onto an applicator comprised of either metal or linen / toile. Metal applicators were created in numerous shapes and forms (cylindrical, spherical, round, etc.) to achieve treatment goals, and the radium salt applied using approximately 10 cg of radium salt per square centimeter. Once dried, a coating of resin would be applied to seal and fix the radium. Toile applicators provided no filtration, were fragile, and had to be handled with great care. In some cases, a toile could be sandwiched between thin sheets of lead to make an apparatus that could be applied in the mouth, vagina, or cervix uteri.

A notable example of a metal applicator from this era is Wickham's "radio-uterine apparatus" (Figure 4). The applicator incorporated cylindrical rods of variable sizes that were coated with radium varnish. The rods were affixed to a cup, also with varnish applied, to treat the external cervix when the rods were inserted into the uterus. Lead or silver screens could be placed over the apparatus to provide filtration.

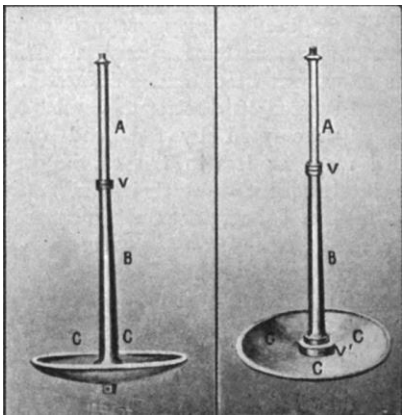

Fig. 4: Illustration of Wickham's uterine applicator [4]

As noted in Section II, much of the clinical use of radium during the first decade of the 1900s was pioneered by dermatologists treating superficial conditions. There was a need to identify appropriate material for creating superficial molds and plaques to facilitate optimal treatment. One relatively well-known solution was the invention of Columbia Paste or "pàte Colombia" that was named after the home country of radiation oncologist A. Esguerra-Gómez, who developed it [19]. Esguerra-Gómez was working at the Curie Institute in Paris and described Colombia Paste in a 1922 French language publication, as a mixture of beeswax, paraffin, and sawdust [20]. Esguerra et al. noted, "Surface Curiethérapy, though simple in appearance, is in reality very delicate to perform correctly. The number of sources to be used, their arrangement relative to one another, their strength, their filtration, and the distance from the skin at which the tubes must be placed are all problems that must be carefully considered." The material could be heated into a pliable state (48 °C) and molded to patient anatomy as required. A hot awl could be used to punch holes for attaching string or to create openings in the material. Similarly, a heated piece of iron was used to melt cavities in the material for source placement, and a backing mixture of paraffin and beeswax applied to secure the sources. Colombia paste had several advantages: it did not deform at body temperature, was lightweight, was smooth, could be washed with soap and water, could be sterilized by heating to 120 °C, and could be melted down and reused indefinitely [20]. Colombia Paste was eventually available commercially in different thicknesses; however, it was difficult and costly to import, and similar products were produced, including radon wax described by I. I. Kaplan, a physician at Bellevue Hospital in New York, and produced in the United States [21]. Kaplan's 1930 publication included a figure illustrating the variety of applicators that could be constructed (See Figure 5).

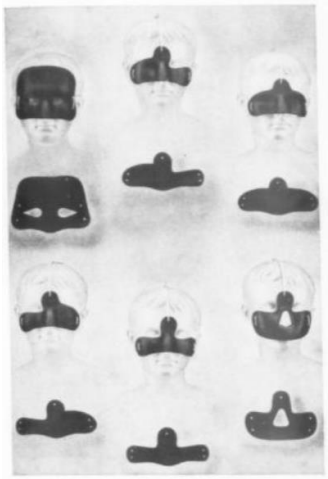

Fig. 5: Applicators made with radon wax, a variant of Colombia Paste [21]

In a 1922 article, B. Allen described a concave applicator designed to hold an applicator tube-style radium source over the eye for the "treatment of cataracts" [22]. The device, shown in Figure 6, was intended to be comfortably inserted under the eyelids to "obviate… the necessary tanning of the skin … when applying the radium externally." Dr. Allen was a pioneering radiologist working in Iowa City. Unfortunately, the article did not include the treatment paradigm for this clinical setting, *i.e.*, prescription dose and pattern, or the expected efficacy.

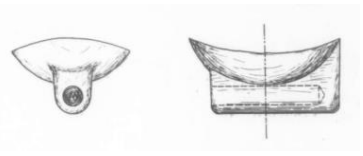

Fig. 6: Illustration of an applicator for the treatment of cataracts [22]

As noted repeatedly above, radium was extensively utilized to treat skin disorders during this era. Reporting on work performed at Memorial Hospital in New York City, D. Quick and F. M. Johnson, a clinical assistant, described an apparatus that captured radium emanations in a small (5 mm diameter), thin, glass bulb [23]. The bulb was sealed into a steel cone using paraffin and attached to a 45 cm pliable metal rod. During clinical use, the operator would be positioned behind a board lined with 6 mm of lead that included an observation window and holes for the passage of the applicator. (Figure 7) Quick and Johnson noted that unfiltered radiation from radon sources (with higher specific activity compared to radium) allowed for rapid treatment of superficial lesions. After three weeks of collecting radium emanations, "as many as 40 or 50 cases may be disposed of in an afternoon" [23].

Fig. 7: Treatment of skin lesions through a shielded board (to protect the operator) using radium emanations [23]

In a subsequent 1923 article, N. T. Beers, a New York City-based dermatologist, described a radium-based applicator intended to treat "small lesions about the face" that was inspired by the work of Quick and Johnson [24]. Beers employed radium instead of radium emanations; however, in lieu of a large applicator with a traditional window screen, he employed a 1 cm diameter radium element embedded in a glaze that had mechanical threading on the back. This element could be attached to a customized applicator, and Beers noted that a T-shaped support made of soft lead could be used to permit easy molding and placement (see for example Figure 8).

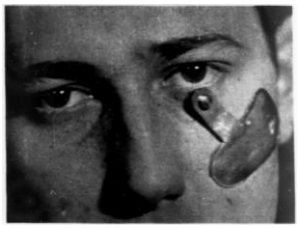

Fig. 8: The Beers lead finger-plate applicator near the eye [24]

As an improvement and modification of the bottle corks originally used as colpostats at the Curie Institute, I. I. Kaplan described an H-shaped apparatus comprised of two gum rubber cylinders (3 cm long, 1.5 cm in diameter) connected by a 10-cm long spring that was also covered in vulcanized rubber [25]. The spring was "just tense enough to spread the cylinders apart in the vagina, and keep an even pressure against the fornices and cervix." Kaplan noted several advantages over the use of cork colpostats, including that it could be sterilized, did not absorb body fluids, and did not require the use of string, among others. From a dosimetric perspective, Kaplan noted that the parallel orientation of the cylinders allowed for "crossfiring" when abutting the cervical lesion.

At the Thirteenth Annual Meeting of the American Radium Society, R.E. Loucks presented an applicator used for the treatment of urethral caruncle, which was published in 1929 [26]. Treatment was delivered via a 25-mg radium tube in a 0.5-mm silver capsule, placed within a 1-mm brass tube, and covered with a rubber cot (0.5 mm). The source is placed between two dummy sources positioned on either side of the meatus, and above a vaginal obturator used to hold the entire assembly in place (See Figure 9).

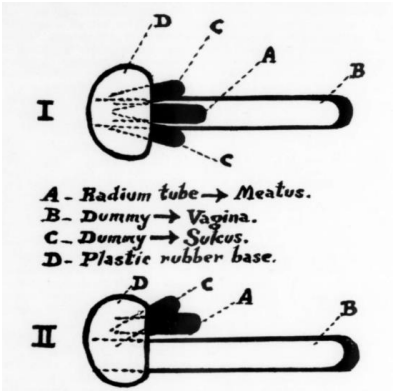

Fig.9: Illustration of the urethral caruncle applicator [26] using overhead (I) and lateral (II) views

Dr. Loucks described two patient cases that experienced at least two years without pain or discomfort following treatment-related reactions. Of note, publication of this presentation in the *American Journal of Roentgenology and Radium Therapy* included a summary of the discussion that took place at the meeting following the presentation, during which some physicians argued for the role of

electrocoagulation or surgery while others supported the use of radium. One commentor, Dr. O. L. Norsworthy of Houston, TX, reported use of the Clark cervical applicator in treating the meatus of the urethra. They similarly used a heavily filtered, 25-mg radium source for two hours.

A variation of the Clark applicator was described in a 1928 publication by H. Swanberg [27]. The Clark applicator was a single T-shaped applicator that replaced the traditional combination of a uterine applicator and colpostat favored by the so-called "French School" of radium use championed by C. Regaud at the Curie Institute of Paris. The Clark applicator used 1 mm of brass covered by 0.5 mm of aluminum, while Swanberg's variation utilized a gold alloy for additional filtration to protect the vaginal mucosa. The uterine channel could be adapted to patient-specific lengths as shown in Figure 10. Swanberg recommended that the applicator be used with colpostat described by Kaplan (above) to best follow the treatment paradigm recommended by Regaud.

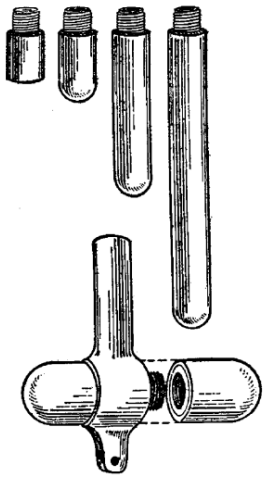

Fig. 10: Illustration of the Swanberg variation of the Clark Applicator [27]

A 1930 discussion of the role of radium in treating thyroid disease by S. Ginsburg included a general overview of the technique and a collection of twenty-five patient cases [28]. The authors first used a linear "radium block" of balsa wood with radium sources attached in a parallel array, which evolved into a semi-circular radium "collar" with small blocks of balsa wood bound with plaster and gauze to conform to the patient's neck (Figure 11).

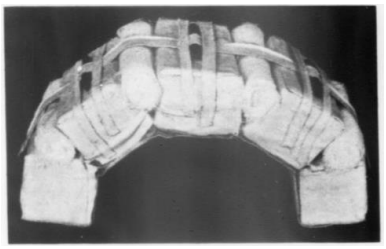

Fig. 11 Radium "collar" employed by Ginsburg to treat thyroid disease [28]

Of note, the treatment paradigm employed by S. Ginsburg was to employ a fractionated course of "one-sixth to one-quarter of the erythema dose … at intervals of five to seven days until a full erythema dose was reached." The patient would then pass an interval of four weeks before being checked for clinical status and metabolic rate. If indicated, the treatment could be repeated. Approximately 20% of the case studies were accompanied by patient before-and-after photographs.

While two applicators discussed above employed radioactive elements inserted into the uterus (i.e., the designs of Wickham and Swanberg), another type of applicator was described by Swedish oncologist J. Heyman in 1936 [29]. Heyman had historically treated the uterine cavity using a tube containing between 35-45 mg Ra using a length that fit the cavity; however, surgical evaluation of failed cases identified that the top of the uterine cavity likely received insufficient dose. Heyman designed an alternate method where the uterine cavity was packed with a number of smaller capsules holding less radium. Radium tubes were 20 mm in length and 2.8 mm in diameter, and were encased in an external capsule with an equivalent thickness of 3 mm of lead. Most patient cases could be treated with 8-12 cylinders, although some treatments exceeded 20 cylinders. Treatments were later standardized using approximately 10 capsules, by performing treatment simulations in leather pouches of different size. A strong thread was attached to each capsule for removal, and special attention was necessary for orderly capsule removal. Figure 12 shows a Heyman capsule and the loading tool, that was designed by R. M. Siebert.

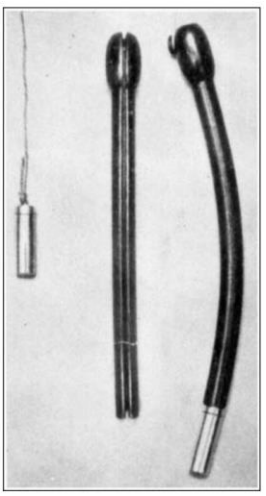

Fig. 12 Heyman capsule (left), empty loading tool (center), and loading tool with capsule (right) [29]

III. Conclusions

This work explored a selective history of brachytherapy practice in the pre-nuclear era, with a focus on the medical use of radium and radium emanations. The discussion was

divided into two sections, one with a focus on the evolution of clinical practice and another with the intent to examine inventions and equipment that enabled medical advancements during that time. Textbooks and publications from the era were explored to gain insight and more contemporary review papers were also cited. Of note, literature produced during the early 1900s incorporated more and more information (and warning) regarding the risks of radium and radiation exposure, which reflected painful lessons learned through individual sacrifices of pioneers and innovators. This work can be used as a starting point for others to further explore this subject matter.

ACKNOWLEDGMENT

The authors would like to thank Dr. Geoffrey Ibbott for the invitation to explore this rich topic and present during the History Symposium at the 2026 meeting of the American Association of Physicists in Medicine.

This work would not have been possible without the vast trove of historical documents that have been scanned and stored in digital repositories for the benefit of future generations and academic research. Many of these documents were captured using optical character recognition, improving interpretation of faded source material and allowing subsequent translation of foreign language material. Google AI was used in some instances to translate foreign language text. This technology further allows appreciation of the original subject matter.

Google, Inc. (Mountain View, CA) scanned a number of resources available through the HathiTrust digital library (https://www.hathitrust.org/). Similarly, the Internet Archive, a non-profit corporation, maintains a digital library of numerous historical journals (https://archive.org/), including many volumes of the American Journal of Roentgenology from the early 20th century (https://archive.org/details/pub_ajr-american-journal-of-roentgenology).

These resources and others like them provide access to documents of historical significance to anyone with a computer, an internet connection, a budding interest, and a little free time.

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