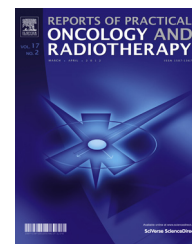


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Review

The contribution of women to radiobiology: Marie Curie and beyond[☆]

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ABSTRACT

Marie Skłodowska-Curie, an extraordinary woman, a Polish scientist who lived and worked in France, led to the development of nuclear energy and the treatment of cancer. She was the laureate of two Nobel Prizes, the first woman in Europe who obtained the degree of Doctor of Science and opened the way for women to enter fields which had been previously reserved for men only. As a result of her determination and her love of freedom, she has become an icon for many female scientists active in radiation sciences. They are successors of Maria Curie and without the results of their work, improvement in radiation oncology will not be possible. Many of them shared some elements of Maria Curie's biography, like high ethical and moral standards, passionate dedication to work, strong family values, and scientific collaboration with their husbands. The significance of Tikvah Alper, Alma Howard, Shirley Hornsey, Juliana Denekamp, Helen Evans, Eleanor Blakely, Elizabeth L. Travis, Fiona Stewart, Andree Dutreix, Catharine West, Peggy Olive, Ingela Turesson, Penny Jeggo, Irena Szumiel, Eleonor Blakely, Sara Rockwell and Carmel Mothersill contribution to radiation oncology is presented. All the above mentioned ladies made significant contribution to the development of radiotherapy (RT) and more efficient cancer treatment. Due to their studies, new schedules of RT and new types of ionizing radiation have been applied, lowering the incidence of normal tissue toxicity. Their achievements herald a future of personalized medicine.

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“Therapy should be permanently backed up by scientific research without which no progress is possible. Moreover, the search for pure knowledge is one of the important needs of mankind...”.

Marie Curie (From Marie Curie's speech made at the opening of the Radium Institute in Warsaw, May 1932)

In 1911, Marie Skłodowska-Curie was awarded her second Nobel Prize for the discovery of radium. Her pioneering work demonstrated that radiation is a powerful tool with a wide range of potential applications, which include a range of diagnostic and therapeutic medical procedures. Marie Curie has left a great deal to the world. Her work led to the development

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of nuclear energy and radiotherapy (RT) for the treatment of cancer. She also improved the image of science. Marie Curie, the first woman in Europe to obtain the degree of Doctor of Science, the first female professor at Sorbonne, opened the way for women to enter fields which had been previously reserved for men. As a result of her determination and her love of freedom, she has become a role model for 20th century female radiobiologists presented here and who continue Marie Curie's legacy development of radiotherapy. It is therefore worthwhile to highlight her many achievements and her personality, which make her a role model for scientists today.

Marie Skłodowska-Curie was born in Warsaw, Poland, on 7 November 1867, and because women were not allowed to study at Polish universities she left the country to continue her education in France. She won her licenciate in physics at the Faculty des Science at Sorbonne already in 1893, and in mathematics a year later.

In 1894 she was introduced to Pierre Curie (1859–1906), a French physicist. Soon after, Pierre realized he had found a matching soul and wrote to Marie: "How wonderful would it be if we could spend our lives together, following our ideas. Your patriotic ideas, and our common ideas of humanity and scientific research". Their marriage (25 July 1895) marked the beginning of a remarkable partnership. They worked in an old wooden shed, with a skylight roof, a former prosectorium of a medical school. Pierre concentrated on physics, Marie on chemistry, she was mainly occupied with isolating uranium salts from tones of ores. Marie published her first research paper on magnetism of tempered steel.¹ She presented the results of her solo work on Becquerel's rays and suggested the existence of a new element. Pierre Curie joined her research work in March 1898. The Curies' investigation of the radiation in uranium ore led, in 1898, to the discovery of two highly radioactive new chemical elements, polonium (named by Marie in honor of Poland) and radium.^{2,3}

Marie struggled to obtain pure radium in the metallic state. When this was achieved, the Curies idealistically resigned from the right to patent the radium isolation method. They published all the results of their studies along with the detailed manufacturing processes and offered free information on the subject. Marie Curie wrote: "Radium is a chemical element, a property of all humans".

In 1903, Marie Skłodowska-Curie received both her doctoral degree for her studies on radioactive substances and, together with her husband and Henri Becquerel, the Nobel Prize in physics. But the prize nearly remained in the male company. Only Pierre Curie and H. Becquerel were initially nominated as candidates, while Marie's contribution was ignored. Marie's role was finally acknowledged after Pierre Curie wrote to the nominating committee saying that either he and his wife were honored together or he would resign from his candidacy. This is the example of the Curies' supportive relationship.

After Pierre Curie's sudden death in an accident on 19 April 1906, Marie was appointed to succeed him as head of the physics department at the Sorbonne.

In 1911, she received the Nobel Prize in chemistry for her work on the isolation of metallic radium. In the same year she took part in the Solway Conference, where she was the only woman amongst men-scientists that included Niels Bohr, Max Planck and Albert Einstein.

Due to Marie Skłodowska-Curie's efforts, the Radium Institute in Paris (Pierre's dream) was founded in 1912. In 1914, Marie became head of the Curies Pavilion and worked there until her death. The social impact of Marie Curie's work can be seen during the World War I, when she organized a mobile radiographic unit and took it to the battlefield where she frequently operated it herself examining the wounded and training radiographic assistants. At a rough estimate, as a result of Marie Curie's involvement more than 150 radiologists were trained at her courses; over 200 X-ray laboratories (including 20 mobile units) were organized for military hospitals, and more than a million soldiers were helped by radiography before surgery.

In 1921 and 1929, Marie Curie made two triumphant journeys to the United States. During the first trip, the President of the United States, Warren Harding, presented her with a gram of radium that had been bought by American women. She donated it to the Radium Institute in Paris. From the second trip to the United States (1929) she brought money to buy radium for the Radium Institute in Warsaw. Both decisions were examples of her engagement in charity work.

In 1922 she was appointed member of the International Commission on Intellectual Co-operation by the Council of the League of Nations. Without regretting her early attitude to resist patenting her own ideas, she became an advocate of scientists' right to patent their discoveries and inventions. She also campaigned for free access to international scientific literature, for internationally recognized scientific symbols and standards and for free international exchange of scientists.

In spite of her commitment to France, Marie Curie always maintained close contact with her native country. Due to her generosity and initiative, the Radium Institute in Warsaw was founded in 1932, with its foremost task of utilizing the healing properties of radium to protect health and save human lives. Marie Skłodowska-Curie died on 4 July 1934 of leukemia caused by prolonged exposure to radioactive substances.

Under Maria Skłodowska-Curie's guidance, about 483 scientific publications were published, and 34 doctorates were awarded. The Institute of Radium provided treatment with radium to about 8000 patients. She was widely acclaimed for her scientific achievements and granted numerous awards and distinctions, honorary degrees from many universities and honorary memberships of learned societies. Apart from scientific achievements, she was a happy mother of two daughters; Irene and Eve.

In Marie Curie's time, first cancers treated using radium were easily accessible surface and body cavity tumors. Of the latter, cancer of the cervix was the most frequently treated. In the mid-1930s, cancers in many sites were considered to be incurable. But with time the situation changed, owing to, among others, many female scientists faithful to Marie Curie's idea of fight against cancer. Their achievements increased the understanding of cell-killing mechanisms, normal tissue toxicity, effect of dose fractionation and tumor biology and influenced progress in RT. Many of them shared some elements of Marie's biography, including, emigration to a foreign land, high ethical and moral standards, passionate dedication to work, strong family values, and scientific collaboration with their husbands. The best examples could be the cooperation of Tikvah Alper with Michael Sterne, Juliana Denekamp with

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