Theophilus Shickel Painter (1889-1969) [1]

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Theophilus Shickel Painter studied the structure and function of chromosomes in the US during in the early to mid-twentieth century. Painter worked at the University of Texas at Austin[3] in Austin, Texas. In the 1920s and 1930s, Painter studied the chromosomes of the salivary gland giant chromosomes of the fruit fly (*Drosophila melanogaster* [4]), with Hermann J. Muller. Muller and Painter studied the ability of X-rays to cause changes in the chromosomes of fruit flies. Painter also studied chromosomes in mammals. He investigated the development of the male gamete, a process called spermatogenesis, in several invertebrates and vertebrates, including mammals. In addition, Painter studied the role the Y-chromosome plays in the determination [5] and development of the male embryo. Painter's research concluded that egg [6] cells joined with a sperm [7] cell bearing an X-chromosome resulted in a female embryo, whereas egg [6] cells joined with a sperm [7] cell carrying a Y-chromosome resulted in a male embryo. Painter's work with chromosomes helped other researchers determine that X- and Y-chromosomes are responsible for sex determination [8].

Painter was born on 22 August 1889 in Salem, Virginia, to Laura T. Shickel Painter and Franklin V. N. Painter, a clergyman and educator. Most of Painter's elementary and secondary education occurred at home, as he was often sick. In 1904, Painter enrolled at Roanoke College in Salem, Virginia, where his father was a professor of modern languages and English literature. Roanoke was a small college and had few science classes. At Roanoke, Painter studied chemistry and physics with no exposure to biology, and he graduated with a Bachelor of Arts degree in 1908.

After graduation in 1908, Painter received a scholarship to study chemistry and entered Yale University [9] in New Haven, Connecticut, as a graduate student. In Lorande L. Woodruff's lab at Yale, Painter studied microscopic life in hay infused with pond water. The hay infusion was Painter's first exposure to biological studies, which he then pursued in his subsequent academic career. Painter finished his chemistry studies and received a Master's of Arts in chemistry in 1909, but he changed his field from chemistry to zoology for his doctorate.

Still at Yale for his doctorate, Painter studied with his supervisor Ross G. Harrison, who developed methods to grow embryonic cells in tissue culture, and with Alexander Petrunkevich, who studied spiders. For his doctorate, Painter focused on the spermatogenesis of the jumping spider (*Maevia vittata* [10]). After receiving his PhD in 1913, Painter studied with Theodor Boveri [11], who developed the chromosome theory of inheritance, at the University of Würzburg[12] in Würzburg, Germany, and at the Marine Zoological Station at Naples (*Stazione Zoologica* [13] *Anton Dohrn di Napoli*) in Naples, Italy. In Naples he studied the process of cell division or cleavage of developing sea urchin [14] (*Echinus melo* [15]) eggs.

Painter returned to Yale as an instructor of zoology from 1914 to 1916, and in the summers, he taught a course on invertebrate zoology [16] at the Marine Biological Laboratory [17] in Woods Hole [18], Massachusetts. At Woods Hole [18], Painter met Anna M. Thomas from Philadelphia, Pennsylvania, a student in one of his classes at Woods Hole [18] in 1914, whom he married on 19 December 1917, and with whom he had four children. In Woods Hole [18], Painter also met the head of the Zoology Department at the University of Texas at Austin[3], John T. Patterson, who offered him an academic position. In 1916, Painter accepted the position at the University of Texas at Austin[3], where he worked with Patterson for the rest of his academic career.

Painter served in the US National Guard in New Haven, Connecticut, until September 1916. He then went to Austin to teach zoology, but military service interrupted his research. With the onset of World War I [19], the US Army Signal Corps commissioned Painter as a first lieutenant in 1917 and sent him to Toronto's Imperial Flying School in Toronto, Canada. Painter returned to Austin to establish a ground school of aviation in Austin, Texas. He then served as a member of the academic board of the Austin Academy of Aviation in Austin, Texas. In April 1919, Painter retired as a captain in the Reserve Corps.

After the war, Painter returned to the University of Texas at Austin and resumed research and teaching. In 1921 Painter became an associate professor and he advanced to full professor in 1925. After military service, Painter resumed spermatogenesis studies, this time in vertebrate animals like the common lizard (*Anolis carolinensis* [20]), rather than in invertebrates like the sea urchin. Embryologist Carl G. Hartmann in the zoology department at the University of Texas at Austin[3] studied the reproduction of the opossum [21] (*Didelphis virginiana* [22]), which offered an opportunity for Painter to switch from studying the chromosomes of spiders, marine organisms, and lizards, to mammalian chromosomes.

In the 1920s, not many scientists had studied mammalian chromosomes. Scientists assumed that mammals had sex chromosomes that corresponded to the chromosomes of insects [23], where XX was female and XZ was male, but there was no evidence for this assumption. Cytological studies, at that time, used tissues that had first been fixed in alcohol or formaldehyde, embedded in paraffin, sectioned, and stained with a dye to show the internal structure of cells. Because the opossum [21]'s Y-chromosome was so small, the scientific community thought that the male opossum [21] lacked a Y-chromosome and had an XO chromosome type, in which 'O' represented the absence of a chromosome or the null type. Painter invented a knife with multiple blades by mounting multiple safety razor blades in parallel to cut up the testis into thin sections immediately after the organ removal. His technique improved the stabilization of the tissue, called fixation, and enabled a more detailed view of the cell structure. Painter used that technique to show that the male opossum [21] had a small Y-chromosome that paired with the female's X-chromosome. In 1921, Painter published "The Y-chromosome in Mammals," in which he described the XY chromosome type in the male opossum [21]. He confirmed that both the male and female opossums had twenty-two chromosomes.

Painter studied the sex chromosomes of humans [24] in 1923, and sex chromosomes of the primates brown cebus (*Cebus capucinus* [25]) and rhesus monkey [26] (*Rhesus macacus* [27]) in 1924. In those studies, Painter confirmed the XX female and the XY male sex chromosome in both human and primates. The number of chromosomes in humans [24] was unclear at the time of Painter's research, as scientists reported the number to be from forty-six to forty-eight, with most investigators reporting forty-eight human chromosomes. In 1923, Painter reported forty-eight on evidence of what he called his best cell, or the best section from human testes [28], perpetuating an error that lasted until the 1950s. In 1956 Joe H. Tijio and Albert Levan at the Institute of Genetics in Lund, Sweden, confirmed that the actual number was forty-six chromosomes for humans [24].

Genes located close together on a chromosome are often inherited together and are called linked genes [29]. Geneticists used breading experiments to calculate how often traits were inherited together to determine how far apart genes [29] were on a chromosome. From the breeding crossover frequencies, geneticists built linkage maps or genetic maps to determine the structure of the chromosomes. In the 1920s and 1930s, geneticists hypothesized that genes [29] lined up on the chromosome in a linear fashion, and they used breeding crossover frequencies to determine the relative distance between genes [29]. Painter studied the structure and function of chromosomes by observing stained chromosomes under the microscope [30]. Painter correlated cell changes with the breeding crossover data. Natural changes, or mutations, in the genes [29] or chromosome were rare. It took many breeding experiments to observe a change in the expression of the chromosomes. In 1927, Muller published "Artificial Transmutation of the Gene" describing the change that X-rays induced in the fruit fly genes [29], for which he later won the Nobel Prize.

At the University of Texas at Austin [3], Painter and Muller collaborated on the study of the parallel behavior of genes [29] and chromosomes. They correlated linkage maps for fruit flies with data about how fruit fly chromosomes rearranged themselves in cells after the researchers had irradiated them with X-rays. In 1929, Painter and Muller co-authored two articles, "Parallel Cytology and Genetics of Induced Translocations and Deletions in Drosophila [31]" and "The Cytological Expression of Changes in Gene Alignment Produced by X-rays in Drosophila [31]," which criticized theories of the point-by-point correspondence of linkage maps and the structure of chromosomes. The chromosomes had long areas where no crossovers occurred and other shorter areas where many crossovers occurred.

From 1929 to 1939, Painter published at least fourteen articles on the giant chromosomes of the fruit fly (*D. melanogaster*) larvae's salivary gland. Painter co-authored several of these papers with colleagues including Muller and Patterson. In 1939, Painter became distinguished professor of zoology at the University of Texas at Austin.

In the 1950s, new techniques became available to count chromosomes more accurately. New stains such as Feulgen and Giemsa stains, which specifically stained DNA, became available. In 1952, Tao-Chiuh Hsu at the University of Texas Medical Branch in Galveston, Texas, developed a technique for preparing and counting chromosomes. Hsu grew embryonic cells in tissue cultures for several days, treated them with colchicine, a chemical that stops cell division at the metaphase stage, then rinsed them in a hypotonic salt solution before fixing and staining them. In 1956, Tijio and Levan used Hsu's technique to determine that the number of human chromosomes was forty-six rather than forty-eight. In the 1980s, Hsu, at the University of Texas's M.D. Anderson Cancer Center in Huston, Texas, reexamined some of the original preparations, according to which Painter based his erroneous chromosome count. According to Painter's biographer Glass, Hsu found chromosomes that stuck together or clumped, and chromosomes cut into segments by the microtome [32] knife, which made it hard to find any cells that could yield a clear chromosome count.

In 1944, Painter became president of the University of Texas at Austin, a position he held until 1952. After being in an administrative position for eight years, Painter returned to scientific research and teaching. In 1966, Painter retired from teaching, but kept active in research and committees.

In 1934, the US National Academy of Sciences [33] awarded Painter the Daniel Giraud Elliot Medal for his work on the chromosomes in *Drosophila* [31]'s salivary glands. Painter was elected to The Scientific Research Society, Sigma Xi, in 1934. Painter was a member of the American Philosophical Society [34], the American Society of Naturalists [35], the American Society of Anatomists, and the American Society of Zoologists, which he served as president in 1940. In 1969, Painter received the first M.D. Anderson Award for Scientific Creativity and Teaching from the University of Texas M.D. Anderson Hospital and Tumor Institute in Houston, Texas.

Painter died at the age of eighty on 5 October 1969, after returning home from a hunting trip, in Fort Stockton, Texas. Two of his papers, the 1969 "The Origin of Nucleic Acid Bases Found in the Royal Jelly of the Honeybee" and the 1971 "Chromosomes and Genes Viewed from a Perspective of Fifty Years," appeared after his death.

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Subject

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