

Carl Richard Moore (1892-1955)

Carl Richard Moore studied sex hormones in animals in the US from 1916 until his death in 1955. Moore focused on the role of hormones on sex differentiation in animals, the optimal conditions under which males produce sperm, and the effects of vasectomy or testicular implants on male sex hormone production. Moore's experiments to create hermaphrodites in the laboratory contributed to the theory of a feedback loop between the pituitary and fetal gonadal hormones to control sex differentiation. Moore showed that the scrotal sac controls the temperature for the testes, which is necessary for sperm production. He also helped distinguish the hormones testosterone and androsterone from testicular extracts.

Moore was born on 5 December 1892 to Sara Frances Harris and Jonathan Newton Moore on a farm near Brookline, Missouri. On the farm, Moore learned to hunt and fish, and fishing remained a life-long pastime. Moore's family moved to Springfield, Missouri when he was nine years old. There he completed his elementary and secondary education and enrolled in Drury College in Springfield, Missouri as a premedical student.

At Drury College, Moore took a biology course with Charles Haddon Spurgeon, who encouraged Moore to study biology and influenced Moore's later teaching methods. Moore graduated in 1913 with a BS degree in biology. Unable to afford medical school, Moore accepted a position as assistant instructor in biology at Drury College for the salary of one hundred dollars per year, where he continued to work and study with Spurgeon. Moore earned his MS degree in biology from Drury College in 1914. The summer before completing his MS, Moore took summer classes at the University of Chicago in Chicago, Illinois. Having used Frank Rattray Lillie's textbook *Development of the Chick* in his undergraduate classes, Moore visited the Zoology Department at University of Chicago where Lillie was chairman. Because Lillie spent summers at the Marine Biological Laboratory in Woods Hole, Massachusetts, Moore did not meet him during that summer session.

Upon completion of his graduate degree from Drury College, Moore enrolled in the University of Chicago's Zoology Department. During his studies, Moore took summer classes at the Marine Biological Laboratory, where he met Lillie. With Lillie's mentorship, Moore investigated the effects of sea urchin sperm on urchin eggs once they began to develop without fertilization, a form of reproduction called parthenogenesis. Moore reported that once parthenogenesis began, whether artificially or naturally induced, the introduction of spermatozoa had no effect on the egg, even if penetration of the egg by a spermatozoon occurred. Detailed in his thesis, "On the Superposition of Fertilization on Parthenogenesis," Moore argued that his results challenged Jacques Loeb's hypothesis that fertilization of sea urchin eggs is depended on chemicals introduced by sperm. Loeb, a member of the Rockefeller Institute of Medical Research in New York, New York, had shown in the early 1900s how manipulated sea urchin eggs so that they developed via parthenogenesis. Moore received his PhD in zoology from the University of Chicago in 1916.

After his PhD, Moore worked as an associate in the Zoology Department at University of Chicago from 1916 to 1918. He became an instructor in 1918, a full professor in 1928, and by 1935, he chaired the Zoology Department.

In his early years in Chicago, he divided his time between research and teaching embryology to medical students. His second paper, "On the Capacity for Fertilization after the Initiation of Development," returned to the sea urchin to again challenge one of Loeb's hypotheses. Contrary to Loeb's results, Moore found that the cell division of sea urchin eggs, once artificially arrested, was not re-activated after spermatozoa were introduced into their environment.

In 1916, Moore's research interest turned to sex differentiation after Lillie suggested that Moore try to create freemartins in the laboratory. Born with a male twin, a freemartin is a sterile cow with external female genitalia and internal male gonads. Lillie theorized that the freemartin was a female whose sex differentiation was suppressed or antagonized by her twin's release of male hormones via their shared blood circulation. Lillie's study of freemartins in 1916 led to the theory that gonadal sex hormones were causes for hermaphroditism, or the condition in which both male and female reproductive organs are present. During this research, Moore married one of his laboratory students, Edith Naomi Abernethy on 1 July 1920. They had three children, two of whom survived, Ellen Abernethy and Harris Mason.

Between 1916 and 1955 Moore experimented to make freemartins in the lab. He introduced male hormones into female rats through testicular grafts, and then he bred them. He also grafted testes in-utero on rat and guinea pig fetuses; injected male hormonal extracts through the placental walls of fetuses; and finally, applied male or female sex hormones to opossum young after their birth. From these studies Moore argued that opposition in physiological action between embryonic sex glands didn't cause sex differentiation. Moore's research on the opossum, which he described fully in 1947's *Embryonic Sex Hormones and Sexual Differentiation*, he used to further support his claim that sex hormones played no part in sex differentiation, despite findings to the contrary later in the 1950s.

In his experiments to reproduce freemartins, Moore developed techniques for implanting testes in fetuses. These techniques supported another of his research interests, the rejuvenation theory. In the 1920s, the rejuvenation theory claimed to rejuvenate aging men with young human or monkey testicular implants. In response, Eugen Steinach director of Vienna's Biological Institute of the Academy of Sciences in Vienna, Austria, stated that separation of the vas deferens in senile men and aging animals was able to produce similar rejuvenating effects through an increase in the production of male sex hormones.

Moore and his graduate students tested the rejuvenation theory. Through a number of experiments, including the measurement of bone length and spermatozoön motility, Moore showed that neither testicular transplants nor vasectomy (vas deferens ligation) increased male sex hormones or produced the rejuvenation effects reported by Steinach.

As part of their investigation into the rejuvenation theory, Moore and William J. Quick studied guinea pigs and the condition of testicles placed in the abdomen instead of the scrotal sac. Moore knew that male mammals that possess a scrotum are sterile if the testicles remain in the abdomen instead of descending into the scrotum (cryptorchidism). Moore and Quick's experiments in 1923 and 1924 established that the scrotal sac helped regulate the temperature of the testes, and thus enabled sperm production. Moore and Quick also showed that the testes returned to a functioning state once relocated to the scrotum, and in 1924 they published "The Scrotum as a Temperature Regulator for the Testes."

In 1927, Moore, Thomas F. Gallagher, and Fred C. Koch utilized a testicular extract, or a small piece of tissue removed from the testicle and the sperm cells present in that tissue, prepared by Lemuel Clyde McGee, a graduate student at the University of Chicago, to chronicle how accessory sex glands changed in Brown Leghorn capons after castration. When the testicular extract was administered, the accessory glands recovered to their pre-castration state. Moore, Gallagher, and Koch established that accessory sex glands could indicate male sex hormone or androgen levels. At the Institute of Technology in the Free City of Danzig, which later became Gdansk, Poland, Adolf Butenandt isolated a crystalline hormone from a testicle in 1935, and he named the hormone testosterone.

Unable to produce hermaphrodites in the lab, Moore investigated and theorized about the role of sex hormones. In the 1930s Moore and Dorothy Price proposed that sex differentiation occurred in developing human fetuses as a result of the balance between gonadal hormones and pituitary hormones. Moore and Price provided the first experimental evidence of a feedback loop by injecting anterior pituitary extracts along with sex hormones to castrated animals. Moore and Price described their work in the 1932 article, "Gonadal Hormone Functions, and the Reciprocal Influence between Gonads and Hypophysis with its Bearing on the Problem of Sex Hormone Antagonism." The principle

of the feedback loop contributed to the development of oral contraceptive pills, with which females who ingest female hormones don't ovulate.

Moore authored or co-authored at least ninety articles between 1916 and 1954. As a professor at the University of Chicago, he mentored fifteen master's students and thirty-three doctoral students. Moore's influence extended beyond his laboratory. He was managing editor of the journal the *Biological Bulletin* from 1926 to 1929; he was on the US National Research Council as a member of the Committee for Research in Problems of Sex, the Committee on Growth, and the Committee on Human Reproduction between 1938 and 1955; and a member of the US National Academy of Sciences in Washington, D.C. from 1944 to 1955.

He received the Francis Amory Award of the American Academy of Arts and Sciences in 1942 for his work on the physiology of sperm and the male reproductive tract, and an honorary doctorate from Drury College in 1948. Moore was also the first recipient of the Medal of Award of the Endocrine Society in 1955.

Despite extended hospital stays and failing health beginning in 1948, Moore continued to chair the Zoology Department at the University of Chicago. Moore died on 16 October 1955 at the age of 62.

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