HISTORICAL NOTE

Robert Hooke, Inventor of the Vacuum Pump and the First Altitude Chamber (1671)

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Harsch V. ***Robert Hooke, inventor of the vacuum pump and the first altitude chamber (1671).*** **Aviat Space Environ Med 2006; 00: 000–00.**

Robert Hooke (1635–1709), an assistant researcher to Robert Boyle (1627–1691), invented the first functional British air pump. Applying it to scientific research, Hooke operated the world's first hypobaric chamber in 1671, using it for self-experimentation. He recorded the first physiological observations in an artificial altitude-equivalent environment up to 2400 m. Though Hooke's experiment showed some methodological insufficiencies, his imaginative experimental techniques were remarkable for their time and were indicative of the lively intellectual atmosphere of the Royal Society and the significant contributions of Hooke, who was a member. Two centuries passed before the French physiologist Paul Bert (1830–1886) conducted his famous laboratory-supported investigations of high altitude physiology. Bert played a decisive role in the discovery of the causes of decompression sickness; a contribution Hooke could not make due to the technical deficiencies of the 17th century.

Keywords: history of medicine, Robert Hooke, altitude chamber, medical ethics.

ROBERT HOOKE (1635–1703) was born on 18 July 1635 at Freshwater, Isle of Wight. His father, the Reverend John Hooke, educated him at home. After his father's death in 1648, the 13-yr-old Hooke went to London to work in the studio of the renowned portrait painter Peter Lely (3,9). Thereafter he was enrolled at Westminster School under Head Master Dr. Richard Busby. Here Hooke acquired a mastery of ancient languages and contrived his first flying machines. Also, he later came back with ideas on the "art of flying" and tried, for example, to invent flying machines operated by human muscle power. However, by his own trials and deskwork calculations, he realized that human muscles were not sufficient for flying machines heavier than air (11).

In 1653 Hooke left Westminster for Oxford, where he fulfilled the necessary requirements to take his B.A. and M.A. degrees. The leader of the Oxford scientific club, Dr. John Wilkins, encouraged him in astronomy, mathematics, and mechanics. Hooke was also employed as a chemical assistant by the anatomist Dr. Thomas Willis, where he seemed to have acquired those dissection skills which would be essential in his later researches into respiration (3,6,11). After leaving Dr. Willis around 1658, Hooke became an assistant to Robert Boyle. As a gifted mechanist, Hooke built a functional air pump where the country's leading engineer, Ralph Greatorex, had failed. In 1662, 4 yr later, he was attached to the office of 'Curator of Experiments' to the newly chartered Royal Society of London, in which Boyle, Wren, and Wilkins were Fellows. Hooke was employed for the preparation and undertaking of demonstrations at the Royal Society's meetings (11). Later, he also became a Fellow of the Royal Society. He was appointed to the Gresham Professorship in 1665, where the Society held its meetings. Hooke was never married, and was, therefore, happy to live at the college to the end of his days. In 1666 he was appointed by the City of London authorities to be their Surveyor following the catastrophic London Fire (1,3,11).

Research on Air and Respiration

Boyle published his book, *New Experiments Physico-Mechanical, Touching the Spring of the Air, and Its Effects*, in 1660 (2). He described the effects of reducing the pressure of air in vessels, which had been made possible by the invention of a practical air pump by his assistant scientist Hooke in combination with the newly invented mercury barometer, which was first used by Evangelista Torricelli (1608–1647) in 1643. The Torricelli barometer was a significant contribution to the understanding of physical and physiological effects of altitude and pressure changes. In 1664, Hooke described that the mercury in the Toricellian experiment showed a difference of about half an inch between the reading at the top and that at the bottom of St. Paul's church. On other occasions, he reported about a barometer falling before a storm and a later observed the barometer rising during the city's fire (6).

There are several reports on Hooke's experiments on 'rarefaction' and '(de)compression' of air, 'respiration,' and the relation between pressure and volume of air (3,6). The experiments by Boyle and Hooke proved the proportional relation between volume and pressure, known as "Boyle's law." After its confirmation by Mariotte in 1676, we commonly speak of the "Boyle and Mariotte Law" (12).

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Hooke's bioscience experiments required a functional air pump, like he had constructed for Boyle. His pump is regarded as the first British functional copy of the "German Engine," which was invented by Otto von Guericke (1602–1686) in Magdeburg in 1650 (6,11).

According to Aristotle, it was believed that air must invade all spaces not occupied by one of the other three elements. The existence of a vacuum did not fit in this understanding of the universe. This changed in 1643, when Galileo's pupil, Torricelli, discovered an empty space above the mercury in the sealed glass tube of the world's first barometer. Von Guericke used his air pump to perform the vacuum experiments with the 'Magdeburg Hemispheres,' which needed teams of horses to separate when evacuated. Boyle began his own research into air and vacuum around 1658, depending on Hooke's air pump (3,8).

However, it was difficult enough to maintain the experimental vacuum with Hooke's air pump because of the leaking pistons, cylinders, and valves. Hooke's pump contained three design features, the first of which was a large glass vessel, the so-called 'receiver.' Two brass stoppers were attached to the top of the receiver, enabling experiments which needed clear vision and the ability to ignite and move things (3). Typically, candles and glowing coals were observed to extinguish in the evacuated receiver, and the time elapsed was compared with the survival time of small animals. The air pump experiments did demonstrate that the element air was extremely elastic and capable of much rarefaction and compression. One of Hooke's findings was that a candle burned for a prolonged time if the air in the vessel was compressed; in lower pressure, on the other hand, a reduced burning time was noticed (6).

The behavior of burning candles under sealed conditions was observed on several occasions, although this emphasized early misunderstandings of the nature of combustion. It took another century before Carl Wilhelm Scheele (1742–1786) in 1772 and Joseph Priestley (1733–1804) in 1774 discovered the element oxygen independently of each other. Antoine Lavoisier (1743–1794) shortly thereafter recognized its meaning for oxidation (1777) (12). However, Hooke had in 1662/63 already proposed an experiment of shutting up an animal and a candle together in a vessel to see whether they would die at the same time. In such an experiment the flame went out after 2 min, while the chicken inside remained alive. Other animal experiments were undertaken on birds, fish, and dogs. For example, fish were exposed to open air or in water while air was evacuated from the vessel being studied (6). In 1664 a bird was exposed to lower pressure (decompressed to half that of the room) for a prolonged time of 10 h and survived the experiment initially, but died the next day. After 2 wk the experiment was repeated and another bird was exposed to one-fourth of the pressure for 11 h, and survived. After a later experiment, the different ways of sealing the vessel was found to be responsible for the death of the bird by inhalation of the "smell" of the cement used (6).

Hooke's research into combustion and the air pump naturally led him not only to the physiology of respiration, but also to that of blood circulation. The circulatory physiologist William Harvey (1578–1657) first described the circuit of blood flow, including its circulation through the lungs, where the arterial gases were picked up, resulting in its lighter color of arterial as opposed to venous blood (12). Consequently, Hooke noticed that arterialization of blood in the lungs occurred through the introduction of fresh air. For instance, a vivisection was performed on dogs in 1664 to study the cardiovascular and pulmonary functions. Hooke reported a vivisection experiment 3 yr later in which a dog was examined while "blowing with a pair of bellows and a pipe thrust" into its windpipe. As long as it was ventilated, the dog could be kept alive and the heart continued beating (6). By these experiments Hooke contributed to the pathophysiological understanding of thoracic surgery procedures in the early 20th century.

Construction of the First Hypobaric Chamber

To study the effects of low atmospheric pressure on a human being, Hooke constructed a sealed chamber in 1671. For a limited time, air was evacuated by an air pump being placed outside a large wooden cask. This experiment, in which Hooke experienced pain in his ears and a temporary deafness, made him the first person to be exposed to artificial high altitude. Hooke had already suggested the use of a "Large Rarefying Engine" 4 yr before. In June 1667 he proposed the construction of this experimental device out of wood: "It should be big enough for a man to sit in and cost not more than five pounds." It was mentioned that Robert Boyle approved this project for the Society's use. On 11 July, 2 wk later, the wooden vessel was tested, but was found not to be sufficiently airtight. No follow-up experiments with this early construction are mentioned (6).

At a meeting of the Royal Society on 12 January 1671, Hooke proposed a new design for a low-pressure chamber for human experimentation. It was manufactured within a month and Hooke stated at the February 9th meeting of the Society that he would undergo self-experiments in the chamber first and then report the results regarding the physiological effects on respiration and body temperature. The world's first practical altitude chamber consisted of two wooden tuns (large casks or barrels), one placed inside the other. The outer barrel was filled with water to keep the inner tun airtight. The inner tun was large enough to hold the test subject breathing rarefied air. The tops of both tuns were sealed with cement. The efficiency of the rarefaction experiment could be achieved by the test-subject with a cock connected to the air pump. The desired degree of low pressure could be estimated by the reading of the barometer, which assumed the existence of a light source in the sealed chamber. Hooke reported the use of a candle, which, however, went out after a certain time. Therefore, it remains unclear if further readings of the barometer were possible (6).

Hooke reported on his experiments in the low-pressure chamber at Gresham College at the Society's meeting on 23 March 1671. During his self-experiment he

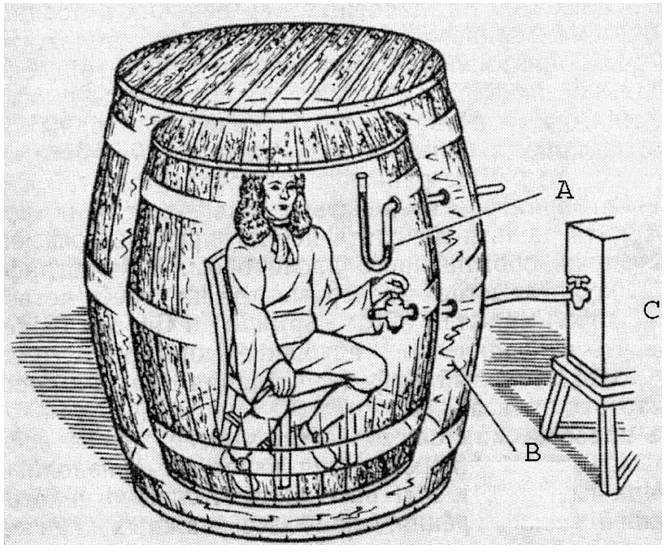

Fig. 1. World's first altitude chamber used by Robert Hooke in 1671. A = barometer, B = water, C = air pump. From Ref. 5, p. 34.

evacuated the barrel's air volume by one-fourth, which was estimated by a gauge (see the Torricelli effect in the barometer in **Fig. 1**) and observed by the Society's president. The total time under lower pressure was a quarter of an hour. Hooke reported some pain in his ears and a temporary deafness that disappeared after "walking a little while up and down" after getting out of the barrel. Other physiological effects were not noticed. In fact, he stated that his heart did not beat quicker, which seems to give an indication that the altitude-equivalent condition of up to 2400 m (0.75 of sea level pressure) was not established for a prolonged time and, therefore, did not affect his physiological responses. The rarefaction process also took time. Additionally, the highest "altitude" level reached could not be held for a prolonged time, because fresh air for supplying the test subject was let in from time to time, resulting in a pressure change. However, the burning candle went out "long before he felt any inconvenience in his ears," giving an idea of diminished oxygen saturation and an increase in CO_2 in Hooke's barrel (6).

Though these experiments show some methodological insufficiencies, Hooke's ingenious experiments were remarkably creative for their time and can be added to the annals of aerospace medicine as the first self-experiments in high altitude physiology and medicine. These experiments were indicative of the lively intellectual atmosphere of the Royal Society and the significant contributions of one of its members, Hooke. It took another two centuries until the French physiologist Paul Bert (1830–1886) made the next efforts for laboratory-supported investigations in the field of high altitude physiology (4,10). Bert is remembered for playing a decisive role in the discovery of the causes of decompression sickness, a contribution which Hooke could not make due in part to the technical deficiencies of the 17th century.

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