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THE DEVELOPMENT OF THE CLINICAL THERMOMETER

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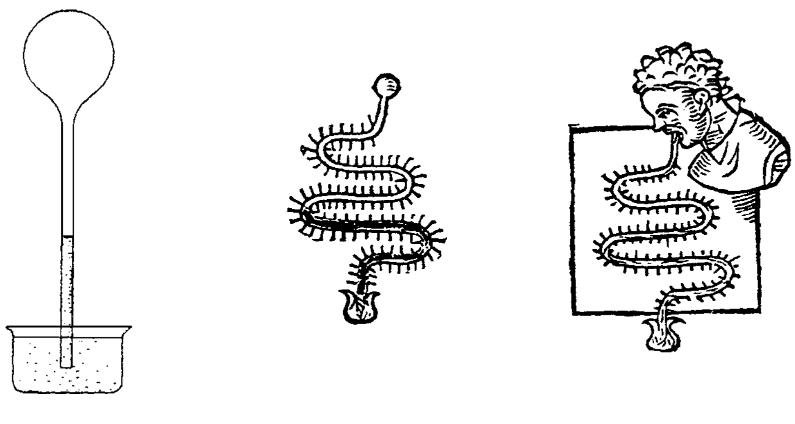
INVENTION OF THE THERMOMETER

The term thermometer was coined in 1624 by a Jesuit priest, Father Jean Leurechon, in his *La Récréation Mathématique*.[1] Before that, devices for measuring temperature were known as thermoscopes.

The invention of the thermometer is attributed to Galileo Galilei (1564-1642). However, the first attempt at quantifying temperature appears to be that of Heron of Alexandria in the second century AD,[2] who invented a glass instrument containing a column of water that was displaced in proportion to the heat applied. His invention remained obscure until shortly after 1592 when Galileo, Professor of Mathematics at Padua, devised a similar instrument (Figure 1a). In his account the air-filled bulb was the size of a 'hen's egg' and the glass column 'two spans long' (about 18", 46 cm) and the 'width of straw'. The lower end of the column was placed in a beaker of water. When the bulb was warmed in the hand, air in it expanded causing a downward displacement of water level in the glass column; conversely the level rose when the bulb cooled.[3] He called the instrument his 'scherzino' (little joke).[4]

The first physician to measure body temperature was Sanctorio Sanctorius (1561-1632), Professor of Medicine at Padua. The principle of his device was similar to that of Galileo, though the tube in this instrument was convoluted and calibrated with glass bead graduations (Figure 1b). Body temperature was measured by placing the bulb in the mouth (Figure 1c).[4] The influence of barometric pressure on these early devices was not readily apparent as the barometer was only invented in 1643.



a b c

FIGURE 1
(a) Galileo's thermometer.
(b) Sanctorius' thermometer.
(c) The Sanctorius thermometer in use.

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In 1631, when French physician Jean Rey developed further a water thermometer he initiated the search for the ideal thermometric substance.[5] Rey's thermometer was a partly water-filled inverted Galileo thermometer with the beaker removed. The upper end was left open so that readings were influenced by evaporation but to a lesser extent atmospheric pressure. In 1641, Grand Duke Ferdinand II of Tuscany, one of the founders of the Florentine *Accademia del Cimento* (Academy of Experiment) developed a hermetically sealed alcohol thermometer.[6] Although mercury (quicksilver) was introduced into the column inside the instrument in 1659 by Ismael Boulliau, a French astronomer and priest, it is usually Fahrenheit who is accredited with the invention of the mercury thermometer in 1714.[4] Isaac Newton's version of the thermometer contained linseed oil: the major disadvantage of linseed oil was its adherence to the glass column, rendering it difficult to read accurately. By the end of the eighteenth century the mercury thermometer had gained popularity because it gave reliable and consistent results although initially it was used more extensively for measurements of air rather than of body temperature.

DETERMINING THE SCALE

The invention of the thermometer brought with it a need for a uniform scale. The respective lower and upper extremes of the Sanctorius thermometer were the temperature of snow and that of a heated candle, while Grand Duke Ferdinand II adopted 'the most severe winter cold' and 'the most severe summer heat' as his extremes. In 1665 Robert Boyle, Robert Hook and Christian Huygens independently suggested that thermometers could be calibrated from a fixed single point, which could be either a freezing or boiling point;[6] 'degrees' would represent a standard fractional change of volume through expansion or contraction from that point. A major drawback of this method was the difference in thermal properties of the many liquids used in thermometers at that time.

Attention soon moved to a two point calibration, a high point and a low point with degrees being interspersed in between. The two points suggested by Honore Fabri in 1669 were the melting point of snow and 'greatest summer heat'. In 1688 the upper point was more precisely defined by Joachim Dalence as the melting point of butter. His scale ranged from -10° (melting snow) to +10° (melting butter). Carlo Renaldi in 1694 first proposed the most precise range when he suggested the freezing and boiling points of water as the two fixed points. The distance between these points was divided into 12 degrees.

In the first important work on clinical thermometry published in 1740, George Martine vividly illustrated the confused state of clinical thermometry. However, by the end of the eighteenth century temperature could be measured with precision for the first time.[7] The two scales which have stood the test of time are those of Fahrenheit and Celsius.

Daniel Gabriel Fahrenheit was born in Danzig, Germany (now Gdansk, Poland). He settled in Holland where, as a physicist, he made meteorological instruments. His interest in the clinical thermometer was kindled by Boerhaave.[8] It was more than ten years after Fahrenheit's invention of the mercury thermometer that the 'Fahrenheit scale' as we now know it was completed. The fixed points chosen by Fahrenheit were modelled on those used by Danish astronomer, Ole Roemer.[9] The lowest point represented a mixture of ice and salt, and the highest was boiling point (steam); Roemer used a 60 degree system to correspond with clocks and geometrical figures. Fahrenheit regarded the many fractions in common readings (body temperature 22.5°) as 'inelegant'.

His scale was designed so that 0 represented the coldest point (ice and salted water), 30 represented iced water without salt and a third point, 96, represented body temperature. Using this scale he determined boiling point of water to be 212°. The difference between boiling and freezing was 182° which he regarded as irrational so he subsequently changed the freezing point to 32°.[10] The Fahrenheit scale is today still the most widely-used temperature scale in the USA, however in the rest of the world the Celsius (originally Centigrade) scale is used. It is named after Anders Celsius, Professor of Astronomy, at Upsala, Sweden. In 1742 he designed a scale of 0°-100°, with 0° being the boiling point of water and 100° the freezing point; the following year the scale was reversed to its present form by Linnaeus Christian, a Swedish botanist in Lyons. Other temperature scales were designed by Reaumur in 1730 and Rankine in 1850. The Rankine (or absolute Fahrenheit) scale continues to be used in some aspects of engineering.[6]

CARL WUNDERLICH (1815-1877)

The use of the clinical thermometer in medicine was given great impetus by Carl Wunderlich. In 1868, while Professor of Medicine in Leipzig, he published his magnum opus *Des Verhalten der Eigenwarme in Krankheiten* (The Course of Temperature in Disease),[11] which showed for the first time that fever is a sign of disease and not a disease *per se*. Wunderlich collected several million temperature readings in the axilla of about 25,000 patients. He used mercury thermometers with a Fahrenheit scale which were 22.5 cms long and took twenty minutes to register. Wunderlich's work on clinical thermometry subsequently influenced the practice of medicine throughout the world.

THE AITKEN AND ALBUTT THERMOMETERS

William Aitken, Professor of Pathology at the British Army Medical School at Chatham, was greatly influenced by the work of Wunderlich in Leipzig. His book, *The Science and Practice of Medicine*, was the first British text to publicise Wunderlich's research and the value of clinical thermometry.[12] Aitken had a thermometer specially made for his use in 1852. Further thermometers were imported from Leipzig by Mr Griffin and were on sale in London in 1863. Thermometers were later made under the supervision of Aitken by a local man, Mr Louis Casella and were of two types: straight and curved (Figure 2).

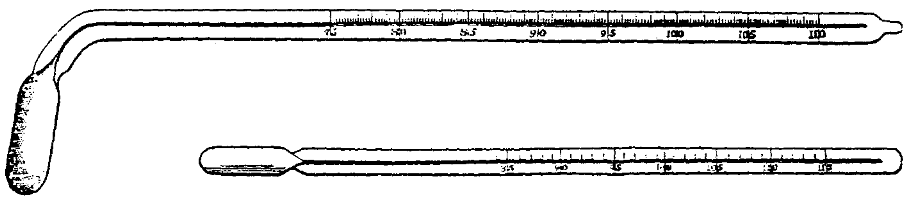

FIGURE 2
Aitken's thermometers, shown one half real size: (a) curved thermometer for *in situ* reading and (b) straight thermometer which could be removed before reading.

The straight thermometer was 25.4 cm long. This thermometer had an air space dividing the mercury column just above the bulb. This air-lock provided a distinct advantage in that the thermometer could be removed from the axilla when it had to be read, making it very convenient. Aitken obtained this idea from Professor Phillips of Oxford, who exhibited such a thermometer at the Great Exhibition of 1851.[12] A constriction in the bore of the mercury column was eventually to prove a better alternative.

The curved thermometer was the shape of a hockey stick measuring 30.5 cms (12") in its long part. The short part was placed in the axilla with the stem projecting forward facilitating reading. This thermometer did not contain an air space in the mercury column as it was intended for *in situ* reading. Both thermometers had a Fahrenheit scale and were carried two in a wooden case under the arm. About five minutes were required for optimal temperature to be reached, but this could be reduced by prior warming of the bulb in the hand.[8,13]

Clifford Albutt, a physician at Leeds General Infirmary, introduced the 'modern' clinical thermometer.[8,13,14] He regarded Aitken's thermometers as too cumbersome and saw a need for a 'pocket' thermometer.* Albutt approached Mr Casella who was 'indisposed to make them', however Harvey Reynolds, a local firm, agreed to do so. The invention of the short-stemmed thermometer was announced by Albutt in 1867 describing it as 'scarcely six inches in length and not much thicker than a stout pencil'. Albutt had misgivings about the Fahrenheit scale (80-115°F); the Centigrade scale was therefore added later but promptly removed when sales dropped. Originally they were made to fit in wooden stethoscopes, but that too was soon abandoned. The price of a thermometer and case was 7s 6d. Albutt thermometers were further shortened to 10.1 cm (4") and then 7.6 cm (3"). The latter were made by Hawksley and others, and exported around the globe.[8]

The original thermometers were round, often rolling off flat surfaces. To obviate the risk of breakage, the shape of the glass tube was altered. An unexpected bonus was the lens effect created by the new triangular shape: magnification of the bore of the thermometer made it easier to read. The lens front thermometer as we now know it was patented by Peroni, a thermometer maker, and was first manufactured in 1878.[16]

A new thermometer known as the 'Repello' was invented in 1901 by Giles Zeal, a glass blower.[16] This thermometer (Figure 3) had a flattened glass bulb filled with mercury at the end opposite the main mercury bulb. An air space was interposed between the registering column of mercury and the mercury in the flat bulb. This arrangement circumvented 'shaking down' as the registering column could be reset by gentle pressure on the flat bulb. It is surprising that this thermometer fell into disuse as it received much critical acclaim in both the medical and lay press.[16,17,18] Another refinement, which did not last, was the Red Reading Thermometer which was introduced in England in 1936 under licence to the Palmer Company of Cincinnati, Ohio. The advantage of the mercury appearing as a red colour was however outweighed by the cost of the red reading tubing.[16]

The many tonnes of mercury contained in glass thermometers eventually find their way back into the environment and ultimately into the food chain. As its environmental

*In 1800 Messrs Allen and Howard, chemists, were selling a pocket-size thermometer for 18 shillings. It was 12.7 cm (5") long and 6mm (0.25") wide with a scale of 80-112°F. They claimed it was so sensitive that the temperature could be read in less than ten seconds.[15]

hazards became more generally appreciated, the mercury thermometer became unacceptable from an ecological standpoint. Sweden became the first country to ban the import or sale of mercury thermometers in 1991.[19]

a
b

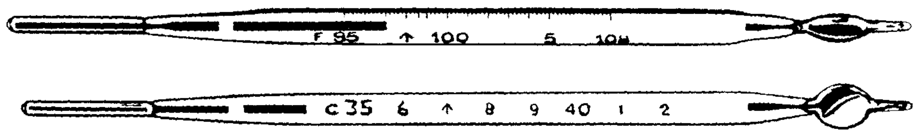

FIGURE 3
The Repello thermometer (length 11cm).
(a) Thermometer showing temperature reading. To reset, the flattened bulb is gently pressed between thumb and forefinger.
(b) A reset thermometer. Note the registering column of mercury has been displaced below the graduations by a column of air.

NEW THERMOMETERS

Since the late 1960s, electronic thermometers have been widely used, and these use thermistors or thermocouples. The thermocouple was discovered first by T.J. Seebeck in 1821 when he noted that when two dissimilar wires are fused at one end and then heat is applied, an electromotive force between the other ends develops. This principle was eventually to be incorporated in clinical thermometers.[6] The thermistor was discovered by Sir William Siemens in 1871 when he noted that changes in temperature resulted in alteration in the resistance to an electric current of elemental platinum. In 1887 H.L. Callandar produced a workable platinum resistance thermometer which was first applied to clinical thermometry by Atwater and Rosa in 1897.[6] Electronic thermometers required much refinement and modification before they became available for general use at an affordable cost.

At about the same time as electronic thermometers became widely available, liquid crystal and 'chemical dot' thermometers were also developed. The wavelength of the light reflected by liquid crystals is temperature sensitive and changes colour accordingly.[6] Liquid crystal thermometers are imprecise and although widely sold for domestic use they are not recommended in hospitals.

The 'chemical dot' thermometer was developed by Weinstein and was first used in hospitals in the early 1970s. It consists of 50 'dots' in a resilient plastic, each acting as an independent unit and representing 0.1°C. The dots contain two organic chemicals which at differing temperatures liquefy causing dye release and blue colour change.[4] This thermometer is unique in that it is the only accurate disposable thermometer.

The most recent thermometers are those used to measure temperature in the ear. Theodor Benzinger in 1959 first showed the close association between tympanic membrane temperature and central core temperature; this is perhaps not surprising as both the ear and the hypothalamus are supplied by the common carotid artery. Pironen was the first to use tympanic thermometry outside the laboratory, thereby ushering in the dawn of tympanic clinical thermometry.[20]

Initially the requirement for probe contact with the membrane posed a clinical problem. This was overcome in the mid 1980s, when infrared thermometers were used to measure the flow of heat (flux) from the surface of the membrane. Despite ongoing controversy about their accuracy, these thermometers are very convenient and are now widely used.[21]

The clinical thermometer has developed from the unsophisticated instrument used by Sanctorius to the high technology instruments of today. The scale has progressed from the crude subjective measurements of the seventeenth century to precise international standards. In the face of equally good alternatives and for ecological reasons the mercury thermometer will be used less frequently in the future.

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