The Ophthalmoscope: Helmholtz's Augenspiegel

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Key Words

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Abstract

The origins of Helmholtz's invention of the ophthalmoscope are found in the ancient observation that the back of the eye appeared black. In 1703, Jean Méry reported that the luminosity of the cat's eye could be seen when the animal was held under water, and Mariotte observed that a dog's eye was luminous but erroneously thought this was because its choroid was white. Prévost made a breakthrough when he deduced it was incident light and not light coming out of the eye. Purkinje and von Brücke used lenses to attempt to see the fundus and almost succeeded. However, it was Helmholtz who created the first useable ophthalmoscope, whose development and clinical application are traced in this paper. One of the greatest physical scientists in many spheres of learning, his biography is briefly sketched.

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'In the whole history of medicine there is no more beautiful episode than the invention of the ophthalmoscope, and physiology has few greater triumphs.'

Edward Loring, American ophthalmologist [1]

Helmholtz (fig. 1) is generally credited with the invention of the ophthalmoscope, which resolved the mystery known to the Romans of why man's pupil appeared im-

penetrably dark. However, the ancients knew that animal eyes could seem luminous. Pliny the Elder (23–79 AD) observed that the eyes of crepuscular animals, such as cats, shine brightly in the dark.¹ The explanation had to wait for many centuries.

¹ Usually quoted from a translation [2].

Fig. 1. Hermann von Helmholtz.

Fig. 2. Helmholtz's ophthalmoscope, 1851.

Fig. 3. Jan Evangelista Purkinje.

Earlier Attempts to See the Fundus

As is often the case, Helmholtz's invention (fig. 2) had its roots in earlier attempts to see the back of the eye, though these were insufficient to permit proper inspection of the human fundus. In 1703, Jean Méry (1645–1722), who worked at the Hôtel Dieu, found that the luminosity of the cat's eye could be seen when the animal was held under water, showing that it was essentially an optical phenomenon [3]. P. de la Hire, 6 years later, thought it was owing to abolition of corneal refraction under water that the incident light rays emerged divergent and were thus seen by the observer's eye. In the fourth essay in his *Oeuvres de Mariotte* (2 volumes, Leiden, 1717), Edmé Mariotte (1620–1684), who was both

physicist and priest, observed that a dog's eye is luminous because its choroid² is white; and the darker choroid in man and animals allowed no clear image. Richter provoked further interest when it was found that luminosity could still be present in a blind eye, and in 1792 Georg Joseph Beer had observed the luminosity of the fundus in aniridia. However, spontaneous luminosity in man remained unexplained.

Bénédict Prévost, Professor of Philosophy at Montaubon in France (1755–1819), repeated Mariotte's experiments, examining the eyes of a cat in the dark, and explained that the retina was invisible:

'It is not the light which proceeds from the eye to an object that enables the eye to perceive that object, but the light which arrives in the eye from it.'

This was an important discovery that dispelled the accepted notions that light came from within the eye to permit animals to see in the dark.

In 1821, the Swedish naturalist Karl Asmund Rudolphi (1771–1832) shone a light into the decapitated cat's eyes and showed that the reflecting eye emitted light along the same line as the direction of the in-going rays.

Twenty-seven years before Helmholtz's work, in 1823, Jan Evangelista Purkinje³ (1787–1869), Professor of Physiology at Breslau, had observed that under certain illumination human eyes could be made luminous: in 1825 Purkinje (fig. 3) started to use lenses to examine the back of the eye. His crucial work, published in Latin, [4] was unrecognized for many years:

'I examined the eye of a dog by using the spectacle lens of a myope and placing a candle behind the dog's back ... I found the light as the source, which is reflected from the concavity of the spectacle lens into the interior of the eye. From there it is again reflected. I immediately repeated the experiment on a human eye and found the same phenomenon' [5].

The pupil too appeared black. The 'beautiful orange glow was reflected when light was thrown into it' (quoted by Albert and Miller [6]). Unnoticed, this was rediscovered independently by William Cumming [7] in England, who, in 1846, wrote 'On a luminous appearance of the human eye and its application to the detection of disease of the retina and posterior part of the eye.' He explained that the axis of illumination and observation had to be coincident to view the fundus. A year later, the Berlin

² Mariotte wrongly assumed that it was the choroid, not the retina.

³ Often spelled Purkyne.

Fig 4. Charles Babbage, F.R.S.

physiologist Ernst Wilhelm Ritter von Brücke [8, 9] (1819–1892) made the same observation:

‘A short time ago in the evening as I was standing between the chandelier and the door in the auditorium of this university, I saw a young man whose pupils were illuminated with a bright red light as he turned to close the door through which he had just passed. ... If one wishes to see this reflex in human eyes ... Take the usual oil lamp with its cylindrical wick and the glass chimney, ... and regulate the wick in such fashion that it burns with a short, intense flame. Then set the lamp close to you, but place the subject 8 to 10 feet away, ... If [the subject] then looks with widely opened lids towards the darkness adjacent to the lamp, or if he slowly moves his eyes to and from, then the pupils will be illuminated with a reddish light, while the iris, in contrast, will appear slightly greenish.’

Helmholtz [10] was later generously to say:

‘Brücke himself was but a hair’s breadth away from the invention of the ophthalmoscope. He had only failed to ask himself what optical image was formed by the rays reflected from the luminous eye. Had it occurred to him, he was the man to answer it just as quickly as I did and to invent the ophthalmoscope.’

Adolf Kussmaul [11] (1822–1902) attempted to see the fundus in 1845. He applied a plano-concave lens of the same power as the cornea to the eye, ‘in an effort to see

the human optic nerve.’ Although Kussmaul failed to view the living fundus, he did show *in vitro* that removal of the cornea and lens rendered the fundus visible, but lack of illumination thwarted his efforts.

There is also a British claim for precedence. Three years before Helmholtz announced his discovery, Charles Babbage FRS (1791–1871)⁴ invented an instrument consisting of a piece of plain mirror, with the silvering scraped off at 2 or 3 small spots in the centre, held within a tube at an angle so that rays of light falling on it through an opening in the side were reflected into the patient’s eye. The observer looked through the clear spots from the other end of the mirror.

As Helmholtz noted, Babbage’s instrument would have worked if a concave lens of 4 or 5 dioptries had been inserted to correct the convergent rays. Babbage (fig. 4) used a plain mirror with a central opening, the first for looking into the eye through an aperture. When he showed it to the ophthalmologist Thomas Wharton Jones, the retina was not adequately seen. Babbage, however, did not pursue his invention. In 1854, Wharton Jones [12], in his ‘Report on the ophthalmoscope’, said:

‘It is but justice that I should here state, however, that 7 years ago [i.e. 1847] Mr. Babbage showed me the model of an instrument that he had contrived for the purpose of looking into the interior of the eye.’

However, Hirschberg [5] has disputed his claim. The major and lasting achievement came when Helmholtz announced the invention of an ‘eye-mirror’ in December 1850.

Hermann von Helmholtz (1821–1894): Early Career

Helmholtz was born on 31 August 1821 at Potsdam. His father, Ferdinand, was a teacher of philology and philosophy, while his mother was a Hanoverian, a lineal descendant of the great Quaker William Penn. He graduated in Medicine from the military medical school in Berlin in 1843, greatly influenced by Johannes Mueller, who had devised the Law of Specific Nerve Energies. Mueller had also trained Henle, Schwann and Du Bois-Reymond. Helmholtz recalled:

‘I recall my student days and the impression made upon us by a man like Johannes Mueller, the physiologist. When one feels himself in contact with a man of the first order, the entire scale of his intellectual conception is modified for life; contact with such a man is perhaps the most interesting thing life has to offer’ [13].

⁴ Babbage was born at 44 Crosby Row, Walworth Road, London, commemorated by a blue plaque on the junction of Larcom Street and Walworth Road. Babbage invented the first mechanical computer: a massive ‘difference engine’ to calculate a series of values automatically by using the method of finite differences. It anticipated the modern computer.

Helmholtz's graduation thesis described the anatomic connection between neurones and nerves. He wrote in 1847 what has been described as one of the great scientific papers of the 19th century: *Über die Erhaltung der Kraft* [On the conservation of energy]. In this he showed mathematically that all forms of energy can be transformed from one form to another, but energy cannot be created or destroyed. He served as physician to the army for several years, before following an academic career in the physical sciences.

Helmholtz's Ophthalmoscope

In his researches Helmholtz noticed that the pupil normally appeared black, but under certain conditions seemed red and emitted light. This convinced him that the emitted light was no more than reflected light. However, advancing from his predecessors, he analyzed how the emitted rays formed optical images [14]. He tried to obtain an optical image of the fundus by devising an instrument that would allow his own eye to be placed directly in line with the light rays entering and leaving the eye. He used 3 microscopic cover glasses as a mirror to reflect light, but they had to be transparent to allow him to see the retina; this he achieved and thus saw the retina in detail.

The announcement was made in a paper presented by his friend Du Bois-Reymond to the Berlin Physical Society on 6 December 1850. However, the text was lost, and on 17 December 1850, Helmholtz, with ill-concealed excitement, wrote to his father:

'I have made a discovery during my lectures on the Physiology of the Sense-organs, which may be of the utmost importance in ophthalmology, ... It is, namely, a combination of glasses, by means of which it is possible to see the dark background of the eye, through the pupil, without employing any dazzling light, and to obtain a view of all the elements of the retina at once, more exactly than one can see the external parts of the eye without magnification, because the transparent media of the eye act like a lens with magnifying power of twenty. The blood vessels are displayed in the neatest way, with the branching arteries and veins, the entrance of the optic nerve into the eye, etc. ... My discovery makes the minute investigation of the internal structures of the eye a possibility. I have announced this very precious egg of Columbus to the Physical Society at Berlin, as my property, and am now having an improved and more convenient instrument constructed to replace my pasteboard affair. I shall examine as many patients as possible with the chief oculist here, and then publish the matter' [14, pp. 23–25].

Helmholtz's first public announcement of the ophthalmoscope was on 11 November 1851 at the Society for Sci-

entific Medicine of Königsberg. His 43-page monograph was also published in 1851 [10]. Helmholtz [15] called his new instrument 'Augenspiegel' (eye mirror). It comprised a lens and a mirror for reflecting light. The instrument was used for examining the retina and adnexa of the eye. He recognized 3 essential components: a light source, a mirror to direct light toward the eye and a device to focus the image on the retina. This instrument was known in England as an 'eye speculum', but Maressal de Marsilly of Calais in 1852 called it the 'ophthalmoscope'. The indirect method of ophthalmoscopy⁵ was the invention of Christian Georg Theodor Ruete [16] (1810–1867).

Technical Variations

There followed many technical variations designed to improve illumination, reflection and refractive errors of both patients and physicians. These are well illustrated by Keeler's papers [17, 18]. Helmholtz's ophthalmoscope used only concave lenses, which had to be changed frequently to suit eyes of different refraction. Rekoss, a technician, introduced a revolving disc carrying a series of correcting concave and convex lenses, whilst Ruete in 1852 established the indirect method of ophthalmoscopy. Many modifications and improvements were to follow. The refracting ophthalmoscope was introduced in about 1870, whilst electric ophthalmoscopes were developed in the 1880s, one of the earliest being that of Juler in 1886 [15, 17]. Search for the ideal source of illumination led to attempts with oil, petrol, gas, daylight and almost every conceivable monochromatic flame. The first instrument to use a bulb inside the body of the ophthalmoscope was made by William Denner and presented to the American Ophthalmological Society in 1885. Many ophthalmologists used stand-mounted ophthalmoscopes for demonstration and later for retinal photography. The popularity of binocular indirect ophthalmoscopy for retinal surgery had to wait many years until Charles Schepens's instrument in 1947, which incorporated reliable illumination. In the 1950s and 1960s several direct ophthalmoscopes with excellent illumination were developed by Keeler, Bausch & Lomb, Heine and Zeiss. The 3.5-volt halogen bulb introduced by the Welch Allyn company further improved illumination [17].

⁵ Indirect: the observer viewing an inverted image through a convex lens between the instrument and the subject's eye. Compare direct method: the instrument close to the subject's eye and the observer viewing an upright magnified image.

Clinical Ophthalmoscopy

Von Graefe facilitated the introduction of the ophthalmoscope to clinical ophthalmology. Some held it might harm the eye. Anagnostakis, in 1854, popularized the instrument in France, whilst in England, it was used and developed by W. Spencer Watson and William Bowman, though many remained sceptical and at first it was utilized infrequently in many countries.

However, a snapshot of its application in the first years after Helmholtz's invention is disclosed in the *Medical Times and Gazette*, 7 March 1857:

'A very useful practical paper on the Ophthalmoscope was read by Mr. Jabez Hogg at the Medical Society of London, on the 28th ult., the chief point of interest seemed to be the great improvement which has ensued in our knowledge of eye diseases since the employment of this instrument. The speakers who took part in the debate which followed the reading of the paper were Mr. Haynes Walton, Mr. Canton, Mr. Power (of the Westminster Ophthalmic Hospital), Mr. H. Thompson, and Mr. De Méric; ... In a preliminary sketch of the history of the ophthalmoscope, it was [stated] in Mr. Jabez Hogg's paper that this instrument is not altogether due, as is usually believed, to the ingenuity of the Germans, but that the idea of its invention originated in the mind of an English surgeon, Mr. William Cumming, who, in the year 1846, read a paper before the Medico-Chirurgical Society upon the best mode of examining the interior of the eye, and detecting the changes occurring in the retina and posterior parts. Mr. Cumming considered that his instrument could be used with more advantage when the pupil was previously dilated by atropine; but in opposition to this view, Mr. Jabez Hogg condemned the use of atropine ... Mr. Hogg had found the instrument invaluable both in hospital and in private practice' [19, p. 241].

Fundal changes in disease were soon recognized by Albrecht von Graefe (1828–1872), undoubtedly the greatest German ophthalmologist of the 19th century, who founded the *Archiv für Ophthalmologie* and the eye hospital in Berlin. In 1855, von Graefe described albuminuric retinitis. By 1860 he had also shown fundal changes in glaucoma (fig. 5) and in retinal arterial embolism; he introduced iridectomy and cataract extraction and described papillo-oedema and its neurological significance. Coccia in 1853 illustrated both retinal detachment and retinitis pigmentosa. Liebreich recognized central retinal venous thrombosis in 1855. However, practising physicians were still slow to appreciate the benefit of ophthalmoscopy. Clifford Allbutt wrote in 1871: 'The number of physicians who are working with the ophthalmoscope today in England may, I believe, be counted on the fingers of one hand.' Allbutt did much to change this with his book *On the Use of the Ophthalmoscope in Diseases of the Nervous System and the Kidneys*,

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Fig. 5. Early illustrations of the fundi from the 19th century showing advanced glaucoma (left) and retinitis pigmentosa (right) [20].

published in 1871, as did *A Manual and Atlas of Medical Ophthalmoscopy* compiled by his friend Sir William Gowers [21].

Helmholtz's Other Contributions

Helmholtz was a polymath of dazzling intellectual range and energy. He was renowned for his co-discovery of the second law of thermodynamics and for his invention of the ophthalmoscope [22]. His most important book on the physiology and physics of optics was his *Handbuch der physiologischen Optik* (1856–1866). He also established the physiology of the cochlea on the principles of sympathetic vibration. Investigating the perception of quality of tone, he showed that quality depends on the order, number and intensity of the overtones or harmonics that comprise the structure of musical tone. He developed the theory of differential and of summational tones. His *Sensations of Tone* (1862) has been described as the 'principia' of physiological acoustics.

Helmholtz made the first measurements of the average speed of propagation of the nerve impulse. Adrian later observed that impulses in each individual fibre are of constant size, but the stronger the stimulus, the greater the frequency of the impulses; he was rewarded with a share in the Nobel Prize for 1932.

Helmholtz lived in Berlin from 1842 to 1849, when he became Professor of Physiology in Königsberg. He published papers on the motion of a perfect fluid: 'Über Integrale der hydrodynamischen Gleichungen ...' and defined vortex lines of fluids. His brilliance was rewarded by the Chair of Physiology and pathology at the Univer-

sity of Königsberg in 1849, after which he concentrated more on electrodynamics, the properties of the non-Euclidean space and acoustics – beyond the realms of this writer and this paper.

In 1855, he took the chair of Physiology in Bonn and in 1858 was appointed Professor of Physiology in Heidelberg. In 1871 he moved again, to the chair of Physics in Berlin. He was elected Fellow of the Royal Society on 24 May 1860 and Fellow of the Royal Society of Edinburgh in 1864, and he received the Royal Society's Copley Medal in 1873.

Helmholtz married twice: firstly in 1849, Olga von Velten, and secondly in 1861, Anna von Mohl; each gave him 2 children. Helmholtz's life was one of austere devotion to science. He became one of the foremost scientific doctors of the 19th century. He was described as:

'The most gracious personality of the 19th century. [And, in him], German warmth and naturalness appear at their best lending a welcome serenity to a fine physical intelligence...' [23].

His ophthalmoscope ranks with the earlier inventions, the telescope (17th century) and the stethoscope (early 19th century). Each provided a source of new information about the human organism and its environs. Eight years after the invention of the ophthalmoscope, von Graefe, its keenest advocate, on behalf of the German Ophthalmological Society presented Helmholtz with a cup at the Heidelberg Ophthalmological Congress. It was inscribed with words [24] that are still fitting today:

'To the creator of a new science, to the benefactor of mankind, in thankful remembrance of the invention of the ophthalmoscope.'

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