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A Brief History of the Ophthalmoscope

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Introduction

It is now more than 150 years since Hermann von Helmholtz's 'discovery' of the ophthalmoscope in 1851. He called it an *Augenspiegel* (eye mirror): the name 'ophthalmoscope' (eye-observer) did not come into common use until three years later; in 1854. At the time Helmholtz, who was only 29, was a professor of physiology and he wanted to demonstrate to his students why the pupil of the eye sometimes appeared black and at other times light (Figure 1).

Prior to his invention there was much speculation as to what lay behind the black hole of the pupil of the eye. Until 1810 there had been many theories about why the eye became luminous under certain conditions. Some thought that the fleeting luminosity was a phenomenon of phosphorescence; others speculated that light absorbed during the day gave off light at night, while others thought that it was the result of activity similar to a firefly and that it was electricity emitted by the retina. Bénédict Prévost, Professor of Philosophy at Montaubon in France, in 1810 explained that the luminosity could only be observed when light entered the eye from without.

Before Helmholtz there had been a number of observers of the fundus in both animals and humans. In 1704 Jean Méry noticed that retinal vessels in the fundus of a cat's eyes became distinctly visible when the animal was placed under water. Jan Purkinje observed the fundus of a dog and then the human eye by using his myopic spectacles (acting as a concave mirror) which reflected light into the eye from a candle placed behind the subject. In 1825 he published his detailed findings in Latin but was unrecognised for his contribution to the knowledge until many years later. Ernst Brücke in 1846 gave an accurate explanation of the red colour of the luminous pupil but it was William Cumming, a young ophthalmologist at the Royal London Ophthalmic Hospital (later to become Moorfields), who in 1846 published a paper stating that every eye could be made luminous if the axis from a source of illumination directed towards a person's eye and the line of vision of the observer were coincident.

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Charles Babbage, the mathematics genius and inventor of what many consider to be the forerunner of today's computer, his analytical machine, was the first to construct an instrument for looking into the eye. He did this in 1847 but when showing it to the eminent ophthalmologist Thomas Wharton Jones, he was unable to obtain an image with it and Babbage, discouraged, did not proceed further (Figure 2). Little did he know that his instrument would have worked if a minus lens of about

Figure 1. Early Helmholtz ophthalmoscope (1851).

Figure 2. Reconstruction of Babbage's ophthalmoscope (1847).

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4 or 5D had been inserted between the observer's eye and the back of the plano mirror from which two or three holes had been scraped. Some seven years later it was his design and not Helmholtz's which had been adopted.
In 1880, Landolt and Snellen had collected 86 types of ophthalmoscope and by the time Hermann von Helmholtz died in 1894, a great number more had appeared, many designed by the best-known ophthalmologists of the day. On the occasion of the 50th anniversary of the ophthalmoscope, an exhibition was put on in Atlantic City, USA, where no less than 140 different designs were shown. By 1913, Edward Landolt reported that 200 models had been produced.

Helmholtz wrote at length about his ophthalmoscope and demonstrated that there were three essential elements in its construction: a source of illumination, a method of reflecting the light into the eye and an optical means of correcting an unsharp image of the fundus. These three elements hold firm today. Of these three ingredients, the source of illumination has perhaps undergone the greatest change in the 150 years of the ophthalmoscope's existence.

This brief history of the ophthalmoscope will examine the changes in its design and construction during the 19th century, and how it developed in the 20th century.

Sources of Illumination

The earliest source of illumination for the ophthalmoscope was a naked candle as used by Helmholtz. The candle was quickly replaced by the gravity-fed oil lamp and then the Argand gas-burning lamp. Attempts were made to harness the source of illumination to the optical viewing system, thereby eliminating one of the variables of alignment. Lionel Beale's ophthalmoscope of 1869 is perhaps the best-known example of this.

In 1879, Thomas Edison was working on his incandescent bulb and this was the start, a few years later, of a radical change in the construction of the ophthalmoscope. The first instrument to use a bulb within the body of the ophthalmoscope was created by Dr William Dennet, who presented his invention to the American Ophthalmological Society in 1885. The idea was sound but the early technology was unreliable, with a variable and short bulb life. Dennett's invention was shortly followed by three other designs, by Thomas Reid of Glasgow, Sir James MaKenzie Davidson of Aberdeen and Henry Juler of London, all in the same year – 1886.

Juler's design involved attaching a light source to the outside of the ophthalmoscope body, close to the mirror with the miniature bulb pointing towards the centre of the mirror aperture. Sight hole flare was a big problem and the life of the bulb was still short-lived.
By the turn of the century, bulb construction and reliability had improved. In 1900, Hugo Wolff produced an interesting ophthalmoscope using a long straight filament bulb, which could be rotated within the instrument. By turning the handle a clear or diffuse patch of light could be projected on the fundus. The instrument was not used as a retinoscope as the straight filament bulb might indicate. This instrument had another unusual feature in that the wheel of lenses was situated in front of the mirror and not behind it as on other ophthalmoscopes.

Methods of Reflecting Light

Helmholtz was the first to observe the human fundus with his *Augenspiegel* in 1851. He had calculated that his line of vision had to be on the same axis as the direction of the illumination. His solution to this problem was to use laboratory cover plates placed one on top of the other and positioned at an angle such that the light was reflected into the patient's eye and the observer could view the fundus through the semireflective plates. He experimented using various numbers of plates, observing that partial polarisation was achieved using three or more.

Helmholtz's 'plates' method of reflection was followed by several ophthalmoscopes using a plano mirror with an aperture scraped from the middle. The first one was Epkens' ophthalmoscope in 1852. Adolf Coccius in 1853, although using a similar mirror, mounted a biconvex lens on an arm in line with the illumination, thereby focusing the light in a more concentrated way into the eye.

The first person to introduce a concave mirror with aperture was Theodor Ruete of Leipzig. His claim to fame was to construct the first instrument for the indirect method of ophthalmoscopy in 1852 (Figure 3). Although Helmholtz had anticipated this method of examination of the eye, it was Ruete who made it a reality. From then on, virtually all ophthalmoscopes could be used in either the direct or indirect mode. To change from one to the other all that was required was to interchange concave mirrors, the one used in indirect ophthalmoscopy being of lower power. Most instruments included a condensing lens of approximately 13D. It is interesting to note that it was not until 1872 that the dioptre was adopted as the international unit of measurement of the power or focal length of a lens or mirror. Until then, English, Prussian or Paris 'inches' were used.

One of the early problems when using the direct ophthalmoscope with the light placed to the side was the need to tilt the mirror at an angle to the line of observation

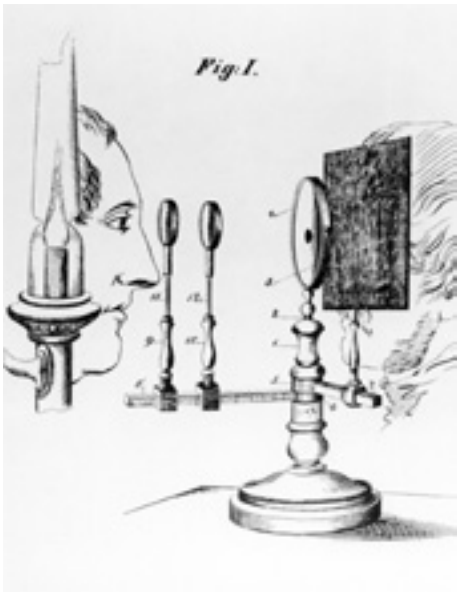

Figure 3. Diagram of Ruete's indirect ophthalmoscope (1852) (from Der Augenspiegel-Göttingen).

Figure 4a. Couper ophthalmoscope (1875).

Figure 4b. Couper ophthalmoscope, reverse side.

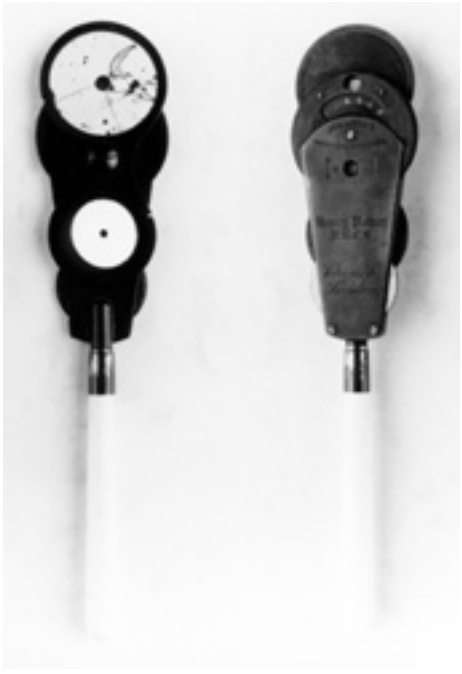

Figure 5. Lindsay Johnson ophthalmoscope (1882).

Figure 6. Couper 'chain of lenses' ophthalmoscope (1883).

for the light to enter the patient's eye. This meant that the observer was viewing the fundus obliquely through the correcting lenses. For low powers this was not a problem but in the higher ranges, it produced a reduction in vision and a shifting of the image due to the prismatic effect.

In 1875, John Couper of the Royal London Ophthalmic Hospital overcame this problem by dissociating the round disc of lenses from the mirror (Figure 4). By this means, the observer was able to look through the centre of the lenses perpendicularly. Couper's design, made by Pickard and Curry of London, went through several models and effectively made redundant the fixed-mirror design. Edward Loring of the USA improved on Couper's model in 1877 with his vertically tilting mirror. This consisted of a round mirror with the sides cut off, rotatable on its vertical axis. There were to be many imitations of this invention over the next 20 years.

The next problem that needed solving was the desirability of having the two concave mirrors mounted at the same time on the instrument instead of having to be taken off and replaced each time. In 1882, George Lindsay Johnson of London introduced an ophthalmoscope with two mirrors fixed to a plate that could be rotated, like the arm of a windmill, around a central pivot (Figure 5). In this way, each mirror could be quickly positioned behind the sight hole, with the smaller 3-inch focal length mirror rotatable around itself for left or right positioning. Later variations of this model featured three or four mirrors, in pairs back to back. Andrew Stanford Morton of London adopted this system and popularised the non-illuminous and self-illuminated ophthalmoscopes bearing his name for over 40 years. But it was not so much the mirror arrangement as the elongated track of lenses for which he is best known.

Correcting Lenses

The first ophthalmoscope that Helmholtz constructed in 1851 had no lenses for correcting errors of refraction in the patient and/or the observer. A year later, Egbert Rekoss, Helmholtz's machinist at the university, added two rotatable discs, each containing a few lenses. Over 150 years later, the Rekoss disc is still used on the majority of hand-held ophthalmoscopes. Although Rekoss had pointed the best way of correcting an out-of-focus image with his wheel of lenses, a number of the early ophthalmoscopes, such as the Coccius (1853), Wilhelm von Zehender (1854), Edward Jaeger (1854) and the Richard Liebreich (1855), used separate individual lenses which were inconvenient and took time to change.

In 1869 Loring, in the first of his several ophthalmoscope models over the years, used three interchangeable Rekoss discs, each with eight lenses. One disc contained concave lenses of moderate powers, another had convex lenses of low powers, and a third consisted of high powers in both concave and convex form. This increased range of lenses enabled the practitioner to estimate the refractive error of the patient during ophthalmoscopy by introducing the lens which produced the sharpest image of the fundus. Any refractive error of the observer would be added to or subtracted from the power shown in the disc lens.

In 1873, Hermann Knapp of New York employed a novel way of extending the range without having to interchange discs. He used two Rekoss discs, which overlapped one at the bottom and the other at the top. The combination of lenses gave a very wide range of powers rapidly and in small jumps.

In 1882, Xavier Galezowski introduced an even more ingenious arrangement. His ophthalmoscope had one Rekoss disc but there were two circles of lenses within it. The outer of the two concentric rings of 19 lenses was concave, whilst the inner ring had 13 convex lenses. To change from one power range to the other, the operator merely moved the whole disc up or down within the ophthalmoscope chassis.

Edward Jackson of the USA, in 1887, employed the whole length of the ophthalmoscope head and connecting stem to mount two sliding racks of lenses, one on top of the other and each with five lenses of concave and convex lenses, which could be moved up and down vertically to align the appropriate power.

Earlier, in 1883, John Couper, in a radical departure from the Rekoss disc, designed the first 'chain of lenses' ophthalmoscope (Figure 6). This brilliantly engineered instrument contained no fewer than 72 individual lenses, each one mounted in a brass cell, and each pushing the next around a track in the ophthalmoscope when driven by a cogwheel placed at the base of the head.

The Couper was the forerunner of Morton's first remarkable ophthalmoscope which was to become the standard 'chain of lenses' design for the next 100 years.

The 20th Century

The advent of the incandescent bulb at the turn of the 20th century transformed the design and construction of the ophthalmoscope. Instead of using an external and

Figure 7. Marple mirror (1906).

Figure 8. Keeler Decagon ophthalmoscope (1930).

remote source of illumination the ophthalmoscope became self-luminous. This did not mean that the non-luminous ophthalmoscope disappeared. Far from it – many designs were still being catalogued in the 1930s. In Japan, even as late as 1912 the Ando sun ophthalmoscope appeared. As its name implies, this relied on the sun's rays as its source of illumination.

In 1915 another major advance took place with the introduction by GS Crampton of Philadelphia of a battery handle for the ophthalmoscope. The ophthalmoscope now became truly unharnessed and could be taken anywhere.

With these two major advances it was no wonder the ophthalmoscope became more sophisticated. Development in the first 20 years of the new century was dominated by an instrument maker, Henry DeZeng of Camden, New Jersey. Others who were to make a major contribution in this period were Dr Wilbur Marple, Charles H May of New York and Alvar Gullstrand of Sweden.

DeZeng was a prolific inventor of many eye and ear, nose and throat instruments but his first love was the ophthalmoscope. This is reflected in his many patents. He made the first practical electric ophthalmoscope, the first with a non-corrosive mirror, the first with illuminated lens indicating numbers and the first commercially produced

Figure 9. Fincham ophthalmo-retinoscope (1930).

ophthalmoscope with a battery contained in the handle. The list goes on, including the first to use filters, a rheostat and standard commercial lamps. The DeZeng Company became part of American Optical in the early 1920s: Henry ended his career with a flourish, producing the Professional and the wonderfully named Knickerbocker ophthalmoscopes!

In 1906 Marple presented his new electric ophthalmoscope to the American Ophthalmological Society. The main characteristic was a U-shaped mirror which, he claimed, eliminated the central corneal reflex and the shadow in the lower half of the fundus (Figure 7). The Marple mirror was to be used on many different models and was popular until the advent of the precentred bulb.

In 1910 Gullstrand, Swedish ophthalmologist and Nobel Laureate, produced his hand-held monocular and binocular ophthalmoscopes and a year later his large stand-mounted, reflex-free ophthalmoscope. The Gullstrand optical design was to nurture important advances in fundus photography with the Nordensen camera in 1925. The first binocular indirect ophthalmoscope had been invented 50 years before by Marc-Antoine Giraud-Teulon of France in 1861. Although the Laurence and Heisch ophthalmoscope of London, built the following year, was significantly easier to use, the binocular indirect method of ophthalmoscopy did not catch on until the middle of the 20th century.

The period between the two world wars was characterised by a flurry of more complex ophthalmoscopes, many of them British innovations, using bulbs of a higher voltage.

In 1926 the Turville–Stewart combined ophthalmoscope, slit lamp and retinoscope was introduced. AE Turville was an optometrist and Dr Stewart an ophthalmologist whom Turville had met at a local radio society. They had laboured in vain to make a table-mounted slit lamp and in the process had learnt a lot from the experience, which helped in their ophthalmoscope design. Turville and Stewart collaborated with Ellis Optical Company of London to produce a series of ophthalmoscopes, including the Westminster and Wide-Angle models.

In the USA, Jonas S Friedenwald introduced his model in 1928 through the American Optical Company. His instrument was large and very long, at over one foot (30 cm). Like the Turville–Stewart and other instruments being introduced at this time, it was multifunctional. American Optical was already busy with its new Giantscope, which incorporated a polarising system to eliminate annoying corneal reflections. Meanwhile, in 1928, in Berlin, Germany, a departure from the normal head-and-handle ophthalmoscope was taking place. Walter Thorner in conjunction with the Emil Busch Company patented a radical design of ophthalmoscope, which made ophthalmoscopy reflex-free in a small instrument. He constructed two models, one a hand-held monocular and the other a binocular ophthalmoscope which could either be hand-held or mounted on a table stand. The Zeiss Company acquired Busch in 1948 and continued to produce the monocular version.

In 1929 Charles Keeler, then only 27 years old, introduced the Decagon, also known as the Master ophthalmoscope (Figure 8). This was the most complex and comprehensive hand-held ophthalmoscope to be put on the market up to that time. It brought two new functions to an ophthalmoscope – the estimation of refractive error including astigmatism and the precise location and measurement of any object within view of the fundus. The Decagon consisted of a Morton magazine of lenses and on the reverse of the instrument a circular drum containing a choice of five optical systems for: (1) direct ophthalmoscopy; (2) retinoscopy and indirect ophthalmoscopy; (3) small beam concentration used for searching for opacities in the media; (4) projection of a refracting graticule with axis determination in astigmatism; and (5) the Morgan retinal graticule for locating and measuring any object seen on the retina. Filters, including red free, white light, daylight and yellow, could be used with any of these systems.

At the same time Edgar Fincham, who with his brother Walter were two of the most brilliant lecturers and optical designers of their generation, patented and had constructed by the Elliott Optical Company his ophthalmo-retinoscope (Figure 9).

The Keeler Company continued its development of more complex ophthalmoscopes with the Cardell polarised ophthalmoscope in 1935. The distinction of this instrument was its use of Nicol prisms to eliminate corneal reflexes. Unlike polarising filters, there was little loss of light. The Iceland spar used in the Nicol prism was cut and assembled in such a way that it allowed the plane-polarised light to be freely transmitted. This was achieved in the Cardell ophthalmoscope by the use of a pair of Nicol prisms, one of which lay in the path of the illuminating system and the other on the viewing axis. A later edition of the ophthalmoscope was to appear in 1950, but this used Polaroid filters due to a shortage of Nicol prisms, as a result of post-war difficulties in obtaining such material.

Nineteen forty-seven was a significant year in the history of the ophthalmoscope for it was at this time that Charles Schepens of Boston constructed his first binocular indirect ophthalmoscope (Figure 10). This method of

Figure 10. Charles Schepens with his original binocular indirect ophthalmoscope (1947) (Trans Am Acad Ophthalmol).

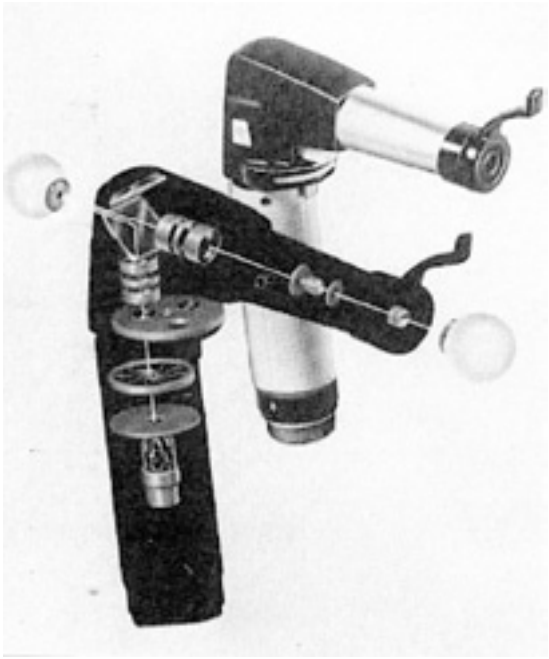

Figure 11. American Optical monocular indirect ophthalmoscope (1968).

Figure 12. Welch Allyn Panoptic ophthalmoscope (2001) (Welch Allyn publication).

examining the fundus was to revolutionise retinal surgery, and as was said at the time, this single invention advanced indirect ophthalmoscopy more than had been achieved in the past 50 years. It soon became the standard method of clinical ophthalmoscopy by ophthalmologists.

As has already been mentioned, the binocular indirect ophthalmoscope was originally invented by Giraud-Teulon in 1861 but because of the difficulty in its use, mainly as a result of the weak source of illumination provided by the gas lamp, it and other models were never popular. Large table-mounted instruments were designed by Zeiss some 30 years before Schepens' head-mounted unit. Wearing the ophthalmoscope on a head band, the operator had both hands free for operating and furthermore, the bulb was powerful, reliable and had a longer life.

From the introduction of Schepens' binocular indirect ophthalmoscope until the present day, the popularity of indirect ophthalmoscopy has increased amongst ophthalmologists and optometrists to such an extent that the hand-held direct ophthalmoscope is hardly used by ophthalmologists.

In 1959 Lorimer Fison of Moorfields, London, working with the Keeler Company introduced the Fison binocular indirect ophthalmoscope, a light and simple-to-use instrument which started an unbroken line of popular indirect ophthalmoscope models for the company.

In 1965 Medical Instruments Research Associates (MIRA) of the USA produced the first small pupil binocular indirect ophthalmoscope under Schepens' and Oleg Pomerantzeff's direction. By an ingenious adjustment of the visual and light paths it was possible for the operator to visualise the fundus binocularly, and with a degree of stereopsis, through the smallest of pupils.

In 1968 a completely new approach to ophthalmoscopy was taken by American Optical Company, with its monocular indirect ophthalmoscope (Figure 11). This instrument produced an erect image and a larger field of view than the conventional direct ophthalmoscope. Its further claim was the ability to examine eyes through a small pupil.

At about the same time, in 1969, a miniature binocular indirect ophthalmoscope mounted on a spectacle frame was manufactured by SOLA in Australia, designed by Schultz and Crock. Five years later the same team added a Galilean loupe, which was incorporated within the optics of the indirect.

As Schepens and others were teaching the advantages of indirect ophthalmoscopy with its wide field of view and stereoscopic vision, further complex direct ophthalmoscopes with powerful illumination were being introduced. Amongst these were two from the Keeler Company, the Measuring in 1951 and the Pantoscope in 1952. Each of these instruments was powered by a 12V precentred bulb with a plano top to eliminate striations in the glass. The Measuring ophthalmoscope had an optical collimator that allowed various graticules to be focused sharply on the fundus. Graticules such as the Morgan 'grid' for estimating and plotting a retinal detachment and the Neame for the precise estimation of blood vessel diameter were part of the six graticules included. The Pantoscope was a multipurpose instrument for direct, indirect and small pupil ophthalmoscopy. The instrument also had a strong adjustable slit beam, polarising filters and other accessories such as an attachment for examining eyes with high myopia.

For the next 20 years, during the 1950s and 1960s, ophthalmoscopes with intense illumination such as the Keeler Pantoscope, Bausch and Lomb's Professional, American Optical's Giantscope and the Zeiss Jena Electric competed at the sophisticated end of the market. But their life was to be suddenly curtailed by the introduction of a new type of light source by the Welch Allyn Company in 1973. This was the halogen bulb operating at 3.5V and producing a brilliant white light. The new generation of ophthalmoscopes used rechargeable batteries and was to be far less complex in construction and operation.

From the late 1970s to the present day all the major ophthalmoscope manufacturers have used halogen or similar bulbs. The Keeler Company converted its popular 'chain of lenses' specialist ophthalmoscope, first introduced in 1955, to halogen illumination, while Heine of Germany used its own kryptogen bulb for its Miroflex and Autofoc ophthalmoscopes. This latter instrument, first introduced in 1973, has an automatic synchronised focus arrangement whereby the illumination and Rekoss disc are coupled so that the aperture and graticules are always sharply in focus on the fundus. Enclosed, dust-free optics is now considered an important feature and is employed by the leading manufacturers.

Miniaturisation in the form of the mini or pocket ophthalmoscope, started by Welch Allyn, has become a useful addition to the practitioner's armamentarium. The choice is wide, not only with the manufacturer, but in sophistication, varying from a no-frills instrument to instruments indistinguishable from their bigger brothers but for the small handle.

Almost exactly 150 years after Helmholtz made public his discovery to the Berlin Physical Society on 6 December 1850, the Welch Allyn Company came out with a totally new design of ophthalmoscope called the Panoptic

(Figure 12). This hammer-shaped instrument is held against the patient's orbit and produces a direct image of 25° field of the fundus, some five times wider than the conventional direct ophthalmoscope. The patented optical design converges the illumination to a point at the cornea, allowing easy entry through small pupils.

This short history of the ophthalmoscope has not attempted to cover all the diverse forms of ophthalmoscope which have appeared over the years. However, mention should be made of the ophthalmoscope's role in pleoptics, with the Visuskop and Euthyscope by Oculus (1958) and in the first hand-held Ruby laser by Keeler, in 1964.

For the future one might anticipate the use of advanced electronics, such as in the scanning laser ophthalmoscope for the sophisticated end of the market, and lifelong sources of illumination, such as light-emitting diodes (LEDs) in the more basic forms of ophthalmoscope.

One of the earliest exponents and enthusiasts of the ophthalmoscope was the American ophthalmologist Edward Loring. He wrote a sentence in the opening chapter of his *Textbook of Ophthalmology* in 1892, which seems apt to conclude this article. "In the whole history of medicine there is no more beautiful episode than the invention of the ophthalmoscope, and physiology has few greater triumphs."

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