In the whole history of medicine there is no more beautiful episode than the invention of the ophthalmoscope, and physiology has few greater triumphs.” Thus wrote American ophthalmologist Edward Loring in the opening paragraph of his *Textbook of Ophthalmology* in 1892, 2 years before the death of Hermann von Helmholtz.

On the 150th anniversary of the invention or “discovery” of the ophthalmoscope (Figure 1) by Helmholtz, we have an opportunity, once again, to laud this outstanding physicist of the 19th century, just as his peers did on the 10th, 50th, and centennial years of this greatest of ophthalmological inventions.

Prior to his invention, ophthalmologists could not view the posterior section of the eye and struggled to explain certain classes of eye disease in which there was a dimness or loss of vision. Suddenly in 1851, the world of ophthalmology was taken by surprise, and a new epoch began. Immediately after the discovery of the ophthalmoscope, men such as Albert von Graefe in Berlin, Germany, Edward Jaeger in Vienna, Austria, and William Bowman in London, England, started using it. Every look into the eye became a discovery.

In 1893 at age 72 years, a year before he died, Helmholtz went to America to attend the World’s Fair in Chicago, Ill, as a representative of the German government. On his way back, he was invited to New York, NY, by Professor Herman Knapp to inaugurate his new clinic before an audience of students and members of the medical profession. Professor Knapp, a former pupil who had begun studying medicine in Germany the very year that the ophthalmoscope was invented, had moved to New York in 1868 from Heidelberg, where he had been a professor for 3 years.

Helmholtz told the well-known story of how 43 years before, he realized that he had solved the mystery of how to penetrate the black pupil of the eye and view the fundus. In 1851, Helmholtz had published his *Beschreibung eines Augenspiegels*, which gave a full account of the optical principles involved. Later he proudly told his father that he had received 18 orders for his instrument from throughout Europe.

By the time of his death, a great number of different ophthalmoscopes had appeared, many of them designed by the most eminent ophthalmologists of the day. Loring, in the introduction to his textbook, states, “[A]lmost every ophthalmologist has taken a hand in perfecting or at least altering the instrument, and from the first I have, perhaps, done more than my share.”

There were no less than 140 instruments on exhibition at a meeting hosted by Harry Friedenwald and Casey Wood in Atlantic City, NJ, on the 50th anniversary of the invention of the ophthalmoscope.

Helmholtz did not readdress the construction of the ophthalmoscope but instead became the greatest physicist and physiologist of the time. He had demonstrated that there were 3 essential elements to the working of an ophthalmoscope: a source of illumination, a reflecting surface to direct light toward the eye, and a means of correcting an out-of-focus image on the fundus.
It was the lack of a strong, stable source of illumination that held up the development of the ophthalmoscope in the 19th century.

Early users of the Helmholtz ophthalmoscope had to put up with a naked flickering candle as a light source. During this first decade, the candle was largely replaced by the oil lamp and then the paraffin-burning lamp.

Various valiant attempts were made at this time to allow the source of illumination to follow the movements of the ophthalmoscope: the first by Ricardus Ulrich in 1854 with his candleholder precariously attached to the observation tube, and the second by Lionel Beale in 1869 with his built-in oil lamp.

Late in the 18th century, Swiss-born physician and chemist Aimé Argand had invented a device that was to evolve into the most common source of illumination during the second half of the 19th century: the gas lamp. In the ordinary oil lamp, combustion was not complete. Argand’s improvement was the replacement of the conventional wick with a ring. The flame became a hollow cylinder with a current of air ascending through the inside so that the burning surface was doubled. Argand’s brother accidentally discovered that a glass cylinder placed as a chimney over the flame steadied it, created a draft, and allowed the flame to yield the maximum amount of light.

The gravity-fed oil lamp was followed by the gas-burning lamp, which worked on the same principle (Figure 2); by 1869, this source of illumination had become the standard. This was fine for examinations in a fixed location such as an ophthalmologist’s office or the hospital, but for domiciliary visits the portable candle or oil lamp, such as the one devised by Joseph Priestley Smith of Birmingham, England, was used well into the 20th century. These lamps incorporated a reflecting mirror behind the candle and a strong convex lens in front to condense the light.

In 1879, Thomas Edison was working on the incandescent bulb. Six years later William Dennett, a New York ophthalmologist, demonstrated this new technology at the American Ophthalmological Society when he presented the first ophthalmoscope that used an electric bulb. It was not a success, mainly because of the unreliability and short life of the bulb.

The following year saw the emergence of 3 ophthalmoscope designs incorporating electric bulbs. Like Dennett, Thomas Reid of Glasgow, Scotland, placed a bulb inside the column of his instrument, but he used a prism instead of a mirror to project the light. Although this model was shown at the 1886 meeting of the Ophthalmological Society of the United Kingdom, it never went into production. Sir James McKenzie Davidson of Aberdeen, Scotland, who was one of the early pioneers of the use of x-ray in ophthalmology, published an article in the Lancet of January 1886 showing a diagram of an electric ophthalmoscope. The third electric ophthalmoscope was designed by Henry Juler of London, England. Unlike Davidson’s concept, Juler’s instrument went into production.

Juler’s design (Figure 3) was the attachment of a light source to the outside of the ophthalmoscope body, close to the mirror with the bulb pointing toward the center ap-
Helmholtz brilliantly devised a method of light reflection by placing superimposed plates of plain glass at an angle to the incident light. Apart from excessive sight-hole flare, this instrument had the same problem of a short bulb life. However, various models using this method became popular.

METHODS OF REFLECTING LIGHT

Haynes Walton of St Mary's Hospital in London wrote in his Practi- cal Treatise on the Diseases of the Eye in 1875, “The modes of reflecting light into the eye are manifold. It is done by unsilvered and by silvered reflectors; by reflectors alone and by reflectors in combination with lenses; by prisms also and by lenses which are themselves silvered.”

Helmholtz had anticipated and that method had caught on rapidly. His glass plates method of light reflection was quickly superceded when Epkens, an instrument maker in Holland, followed by others, used a plano-mirror with an oval-shaped aperture cut out of the middle. Epkens then collaborated with Frans Donders of Utrecht to produce several table-mounted model ophthalmoscopes, \(11^{(p32-37)}\) Four years previously in 1847, Charles Babbage, of calculating-machine fame, had used the same mirror design in his prototype ophthalmoscope. \(12\)

The plano-mirror was an inefficient gatherer of light. In an attempt to concentrate the source of illumination, Adolf Coccius in 1853 used a biconvex condensing lens on an adjustable arm to focus the source of light onto the plano-mirror \(\text{Figure 4}\). Although his first model used a plano-mirror, later this became concave, further increasing the concentration of the light.

In 1854, Professor Karl von Zehender constructed an instrument that had an uncanny resemblance to the second model by Coccius, \(11^{(p12)}\) but it did differ in 2 important respects: the mirror was convex and was made of metal, not glass. Metal provided sharp edges to the sight-hole with no restrictive viewing canal, which often occurred when using thick glass mirrors.

Professor G. Theodor Ruete of Leipsig, Germany, was the first to introduce a concave mirror with aperture, in 1853. This method of reflecting light toward the eye was to last the whole of Helmholtz’s lifetime and well beyond. Ruete used this concave focusing mirror in his new indirect ophthalmoscope \(\text{Figure 5}\), a method of ophthalmoscopy \(13\) that Helmholtz had anticipated and that was to prove of extraordinary importance in ophthalmology. Most ophthalmoscopes thereafter accommodated mirrors and lenses, allowing the ophthalmologist to switch between direct and indirect ophthalmoscopy on the same instrument.

In 1854, Edward Jaeger of Vienna, Austria, introduced an ophthalmoscope with a choice of aperture mirrors with a 4- or 7-in focal length as well as his version of Helmholtz’s glass plates, each of which could be angled toward the source of illumination. \(14^{(p102)}\) Jaeger thereby combined the principles of Helmholtz, Ruete, and others in one rather complicated instrument.

A common problem in all ophthalmoscopes when tilting the mirror toward the light was having to view the fundus obliquely through the correcting lens, as the mirror was mounted flat against the Rekoss disc. This produced a significant reduction in vision and shift of the image when viewing with higher-power lenses.

John Couper of the Royal London Ophthalmic Hospital, Moorfields, overcame this problem in 1875. He mounted his tiltable mirror on a vertical axis so that the source of light could be received by the mirror, which was placed left or right at an angle to the Rekoss disc. The observer was able to view the fundus looking perpendicularly through whichever lens was appropriate. Couper’s first instrument, now in the Institute of Ophthalmology’s collection in London \(\text{Figure 6, left}\), may be his own unique de-
sign. Couper's next model (Figure 6, right) had a more convenient and sophisticated method of swinging the mirror left and right. His tilting mirror was a turning point in the evolution of the ophthalmoscope.14

Couper's idea was followed in 1876 by one from Oliver Wadsworth of Boston, Mass, who designed an angled concave mirror mounted in a disc that could be placed left or right on the head of a Loring ophthalmoscope.4(p346) This conveniently overcame the parallax in earlier instruments and moved the sight-hole and the mirror aperture closer together, allowing the observer to obtain a wider field of view of the fundus.

In the same year, Edward Loring went further than Couper and Wadsworth and produced his vertically held, tilting, rectangular concave mirror (Figure 7). With the sides of a round mirror cut off, a sufficient tilting angle could be achieved while keeping a minimal distance between the sight-hole and mirror aperture. This mirror was extremely simple to use in either the left or right position. Its construction became very popular and was to be incorporated into many other designs during the next 20 years.

Until 1882, the need to use mirrors of more than one focal length for the direct and indirect method of ophthalmoscopy meant the removal of one mirror for another. In that year, however, George Lindsay Johnson of London introduced an ophthalmoscope (Figure 8) with 2 mirrors fixed to an arm that could be rotated to bring the appropriate mirror into position in front of the
sight-hole. The smaller mirror, with a 3-in focal length, rotated around its own axis, and the larger mirror had a focal length of 18 in. Later variations of 3 or even 4 mirrors, back to back, were to dominate the more sophisticated devices such as the Morton ophthalmoscope for the next 40 years.

METHODS OF CORRECTION

Shortly after Helmholtz produced his first ophthalmoscope, a major deficiency became apparent. There was no convenient means of correcting for presbyopia or refractive errors. The optics of the Helmholtz instrument produced a converging image as the rays entered the observer’s eye; this was the main reason that the early instruments used only concave lenses. In 1852, Egbert Rekoss, a university machinist who had made Helmholtz’s original instrument, provided the essential breakthrough by adding 2 rotatable discs, each containing a series of lenses.

Richard Liebreich, while in Berlin, Germany, at von Graef’s clinic in 1855, designed a simple and very popular ophthalmoscope (Figure 9) with a clip mounted on an adjustable arm behind the mirror for a series of unmounted convex and concave lenses. Liebreich was not the first to use this idea; 2 years before, Coccius had done the same.4(p33)

Jaeger’s 1854 ophthalmoscope included 8 concave and 4 convex lenses, with the chosen lens having to be individually inserted into an aperture at the back of the instrument, a tedious and impractical procedure. In 1869, a degree of sophistication crept in with Loring’s first of several ophthalmoscope designs. This instrument had 3 Rekoss discs, each with 8 lenses: one disc contained concave lenses of moderate power, another had convex lenses of low power, and a third was composed of high dioptic power, both convex and concave. This increased battery of lenses allowed Loring to perform refractions as well as ophthalmoscopy. The ophthalmoscope illustrated in Figure 10 has a fourth disc with a further combination of low convex and concave lenses that could have been tailor-made for the operator.

In 1873, shortly after arriving in New York, Herman Knapp, a prolific inventor of surgical and diagnostic instruments, devised an alternative and more efficient way of introducing a wider range of lenses in an ophthalmoscope.16 He was especially interested in carrying out refractions and wanted not only a wider range of lenses but smaller jumps in power. He used 2 Rekoss discs, one with convex lenses and the other with concave lenses, so that the bottom of one and the top of the other overlapped. Knapp had admired Loring’s 1869 model but wanted to avoid the loss of time and the tedious process of assembly and disassembly for each patient.

Xavier Galezowski of Paris, France, who had invented his tubular indirect ophthalmoscope in 1862, designed a very different ophthalmoscope (Figure 11) 20 years later in 1882. This used a single Rekoss disc but with 2 concentric rings of...
lenses mounted within it. The outer ring had 19 concave lenses, and the inner one had 13 convex lenses. Pushing the disc up or pulling it down brought the chosen circle of convex or concave lenses to the center of the viewing aperture. Although Loring had shown the way in 1874, in his Rekoss disc, half of each of the concentric circles had convex lenses, and the other half had concave lenses.4(p330)

Another method of introducing correcting lenses was a design by Edward Jackson of Denver, Colo, in 1887.4(p361) He used the length of the ophthalmoscope head and column to incorporate 2 vertically sliding lens racks, one on top of the other, each with 5 lenses of convex and concave powers that could be used singly or in combination.

In the search for more lenses for refraction, John Couper designed the first “chain-of-lenses” ophthalmoscope (Figure 12).17 This was a brilliant engineering feat, with the ophthalmoscope containing no less than 72 lenses, each mounted in a free-moving brass cell. A cogwheel at the center of the instrument was used to drive the chain of lenses around a groove in the handle and head, with each lens coming to rest precisely in the center of the viewing aperture.

The Couper ophthalmoscope was the forerunner of Andrew Stanford Morton’s first ophthalmoscope, in 1884.5(p119) The Morton device was to become the standard chain-of-lenses design for the next century.

In the attempt to automate the introduction of a wide range of sequential convex and concave lenses in a conventionally shaped head, perhaps the Roth and Callan ophthalmoscopes are the most ingenious. Although both ophthalmologists published details of their instruments in 1864,18,19 Peter Callan’s visit to Berlin most likely allowed him to observe August Roth’s design and then imitate it. Only in detail do they differ.

The change in lens power in the Roth ophthalmoscope (Figure 13), dioptr by dioptr up to 47 dioptries, is achieved by turning a serrated wheel that drives a peg along a wormlike groove, which rotates the Rekoss disc and linked quadrant. The peg is connected to a pointer on the outside that indicates the lens power required.

The size of correcting lenses in ophthalmoscopes varied enormously, from 8 mm in the Landolt ophthalmoscope down to 3 mm in others. One early unidentified ophthalmoscope even had oval-shaped lenses, presumably attempting to pack the maximum number of lenses within the Rekoss disc yet allowing the observer plenty of vertical movement (Figure 14).

A review of the development of the ophthalmoscope in the lifetime of Helmholtz would not be complete without mentioning stand-mounted ophthalmoscopes and the binocular indirect ophthalmoscope.

Many of the best-known ophthalmologists used stand-mounted ophthalmoscopes like the Follin and Liebreich designs for teaching and studying the fundus to produce atlases. The first fundus photograph, published by Oswalt Gerloff of Göttingen, Germany, in 1891,20 had been preceded by meticulously painted fundi showing a multitude of pathological conditions that the ophthalmoscope could now reveal.

For today’s ophthalmologist, the use of the direct ophthalmoscope is less frequent. However, the binocular indirect ophthalmoscope, first introduced in 1861 by the Frenchman Félix Giraud-Teulon,21 is now used as a standard piece of diagnostic equipment. Giraud-Teulon’s binocular indirect ophthalmoscope, which used a solid rhomboid prism to divide the image, had a fixed interpupillary setting. His instrument was followed in 1862 by
a more sophisticated design by J. Zachariah Laurence and C. Heisch of London. Both instruments were hand-held and used for their light source an oil or gas lamp placed behind and to the side of the patient. These instruments were difficult to use and quickly went out of fashion. The popularity of binocular indirect ophthalmoscopy had to wait many years until the introduction of Charles Schepen’s instrument in 1947, which incorporated bright and reliable illumination.

The invention of the ophthalmoscope by Hermann von Helmholtz was enormously exciting for the ophthalmologists of the day and fostered respect for and recognition of ophthalmology as a medical speciality. John Hughlings Jackson, a renowned English ophthalmologist and neurologist, never tired of impressing on physicians the value of the routine use of the ophthalmoscope. He stated that the physician was as much indebted to Helmholtz as the ophthalmologist.

Eight years after the discovery of the ophthalmoscope, Albrecht von Graefe, the greatest advocate of this new tool, presented Helmholtz with a cup at the 1858 Heidelberg Ophthalmological Congress. The cup was inscribed with words that are as appropriate today as they were then: “To the creator of a new science, to the benefactor of mankind, in thankful remembrance of the invention of the ophthalmoscope” (Figure 15).

Accepted for publication September 19, 2001.

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Microvascular Abnormalities and Incident Stroke: The Atherosclerosis Risk in Communities Study

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Background: Retinal microvascular abnormalities reflect damage from hypertension and other vascular processes. We examined the relation of retinal microvascular abnormalities to incident stroke.

Methods: A cohort of 10,358 men and women (aged 51 to 72 years) living in 4 communities had retinal photography and standardized grading for retinal microvascular abnormalities. In addition, the calibers of all retinal arterioles and venules were measured after digital conversion of the photographs, and a summary arteriole-to-venule ratio (AVR) was calculated as an index of arteriolar narrowing (with smaller AVR indicating greater narrowing). Incident hospitalized strokes were identified from this cohort, and validated by case record reviews.

Findings: Over an average of 3.5 years, 110 persons had incident strokes. After adjustment for age, gender, race, 6-year mean arterial blood pressure, diabetes, and other stroke risk factors, most retinal microvascular characteristics were predictive of incident stroke, with adjusted relative risks (and 95% confidence intervals) of 2.6 (1.6 - 4.2) for any retinopathy, 3.1 (1.7 - 5.7) for microaneurysms, 3.1 (1.4 - 6.7) for soft exudates, 2.6 (1.3 - 5.1) for blot hemorrhages, 2.3 (1.0 - 5.1) for flame-shaped hemorrhages, and 1.6 (1.0 - 2.5) for arterio-venous nicking. Relative risk of stroke increased with decreasing AVR (p=0.03). The associations were similar for ischemic strokes specifically, and for strokes in persons with hypertension, either with or without diabetes.

Interpretation: Retinal microvascular abnormalities are related to incident stroke. The findings support a microvascular role in the pathogenesis of stroke, and suggest that retinal photography may be useful for cerebrovascular risk stratification in appropriate populations.

(2001;358:1134-1140)