# Birth of Fiber-Optic Imaging and Endoscopes

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Fiber-optic imaging had a surprisingly long prehistory before its birth as an important optical technology in the 1950s. One fundamental building block, the concept of light guiding by total internal reflection, was already well over a century old. A second, the idea of image transmission through arrays of light guides, went back decades. But it took the invention of low-index cladding to successfully launch fiber-optic imaging and endoscopes.

Swiss physicist and engineer Daniel Colladon was the first to describe light guiding by total internal reflection in 1842 [1]. He demonstrated the effect by illuminating a water jet, an experiment later repeated by John Tyndall. French physicist Jacques Babinet noted that light guiding could also be seen in bent glass rods, but he gave no details. Light guiding in water jets helped light up the "luminous fountains" of the great Victorian exhibitions in the late nineteenth century, and by the early 1900s, glass and quartz light guides were illuminating microscope slides and the mouths of dental patients [2].

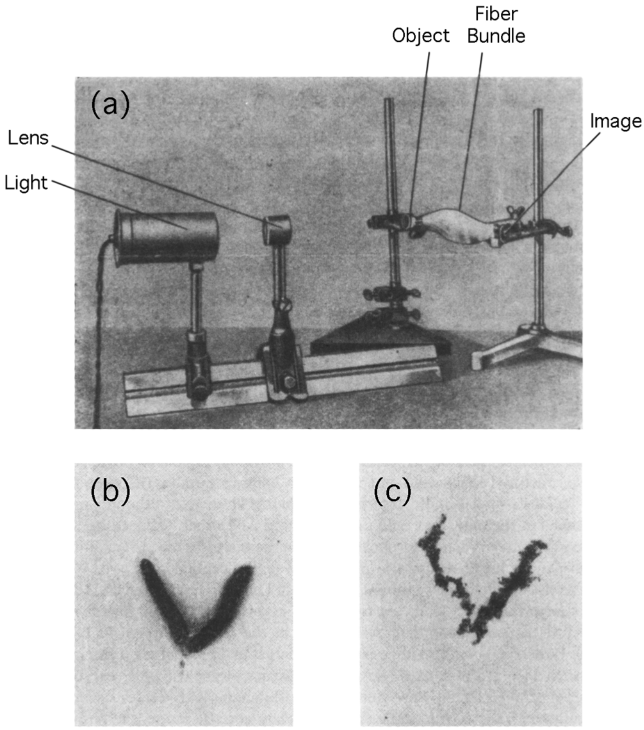
The late nineteenth century also saw the first interest in "remote viewing," or what we now call television. Henry C. Saint-René, who taught physics and chemistry at a small French agriculture school, realized that one way to transmit an image was to project it onto one end of an array of thin glass rods so it could be viewed at the other end of the bundle. He recognized that light would mix within each rod, so the rods had to be tiny to give a good image. In 1895, he wrote to the French Academy of Sciences: "The whole array gives a complete illusion of the object if the diameter of each point does not exceed 1/3 millimeter when the viewer is at a distance of one meter from the image" [3]. The idea was simple and elegant but probably was impractical at the time, and no further records of his work have been found.

In 1926, a British pioneer of mechanical television re-invented the concept. John Logie Baird filed a patent on a method "to produce an image without the use of a lens" by assembling an array of thin transparent tubes. His patent also covered using "thin rods or tubes of glass, quartz, or other transparent material [which] could be bent or curved, or in the case of very fine quartz fibers, could be flexible [4]." He tried to transmit images through an array of 340 metal tubes of 0.1-in. diameter and 2-in. length but abandoned it in favor of spinning disks for mechanical television.

At almost the same time, a young American radio engineer and inventor named C. W. Hansell thought of a new way to read instrument dials that were out of sight. In a notebook entry dated 30 December 1926, he outlined his plans for using a flexible bundle of glass fibers. When his employer, the Radio Corporation of America, applied for a patent, he expanded on his original idea, proposing to use fiber bundles in periscopes, endoscopes, and facsimile transmission. Crucially, he realized that the fibers on the two ends had to be aligned in the same pattern to transmit the image properly. The patent issued in 1930 [5], but by then Hansell had moved on to other ideas.

The first person to make an image-transmitting bundle was a medical student named Heinrich Lamm at the University of Munich in Germany. Lamm had studied with Rudolf Schindler, who had developed a semi-rigid gastroscope that could be bent up to 30 deg. Lamm thought a bundle of glass fibers would be much more flexible and persuaded Schindler to buy him some glass fibers from the Rodenstock Optical Works in Munich.

Lamm combed the glass fibers so they lined up from end to end of the bundle and projected an image of a lamp filament onto one end. In 1930 he recorded an imperfect but recognizable




▲**Fig. 1.** Heinrich Lamm, M.D., combed thin glass fibers and packaged them in a short bundle (a), then focused the image of a light bulb filament (b) onto one end. The fibers were well enough aligned to transmit a recognizable image of the filament (c) to the other end. Both filaments are shown in negative images. (Courtesy of Michael Lamm, M.D.)

image on the other end (Fig. 1). It was enough to prove the principle, although Lamm conceded that the images were not bright or sharp enough to be usable. He tried to apply for a patent, but the German Patent Office told him that a British version of Hansell's patent had just issued.

Lamm described his experiment, but could go no further [6]. The world was sinking into the Depression, and soon Lamm had to flee Nazi Germany. World War II followed. The concept of fiber image transmission did not reappear until around 1950—when three people developed it independently, two of them well connected in optics and the third an independent inventor.

The postwar Dutch navy turned to one of its leading optics specialists, Abraham C. S. van Heel, to develop a new type of periscope as it tried to rebuild its submarine fleet. The German optics industry was in ruins, and neither the United States nor Britain wanted to share their periscope technology with Holland. A professor at the Technical University of Delft, van Heel thought he could solve the problem by guiding light through thin rods of glass or plastic. But his experiments with bare fibers initially got nowhere because of light leakage and scratching.

In neighboring Denmark, engineer and inventor Holger Møller Hansen, like Hansell, wanted to peer into inaccessible places. He thought of using a flexible fiber bundle to transmit images after looking at insects' segmented eyes. An avid experimenter, he first tried drawing his own fibers, then bought some fibers to test. He also discovered that light leaked between fibers if they touched but realized that he could solve that problem if he clad the fiber with a material having a lower refractive index. However, when he sought a material with index close to one, the best candidate he could find was margarine, which did not work well.

Meanwhile, in 1951, British optical physicist Harold H. Hopkins found his inspiration at a dinner party where a physician discussed the horrors of trying to use a rigid endoscope [7]. Hopkins decided that a bundle of flexible glass fibers could do a better job and applied for a research grant to support a research student. When the money came through, he assigned the project to a young student from India, Narinder Kapany.

Hansell's patent had been forgotten and expired in 1947. But the Danish Patent Office found it after Møller Hansen filed his own application in 1951, and rejected the filing. With no support and no luck in finding a good cladding material, he gave up and turned to another invention. With more support, van Heel and Hopkins persevered.

When van Heel sought help with his fiber periscope design, the Dutch government referred him to Brian O'Brien, OSA president in 1951 and director of the University of Rochester's Institute of Optics. The two knew each other as leaders in the parallel worlds of American and European optics; at the time, van Heel headed the International Commission on Optics. As it happened, O'Brien had already been experimenting with light guiding, and he recommended cladding the outside of the fiber with a lower-index material, so no dirt or scratches spoiled the total reflection, and light could not leak out if fibers touched. He had gotten the idea from his studies of light guiding in retinal cells, which had earned him OSA's Frederick Ives Medal in 1951 [8]. Van Heel quickly embraced the idea, and the two promised to keep in touch after their October 1951 discussion.

When he returned to Delft, van Heel tried coating fibers with beeswax and plastic. Both cladding materials improved fiber transmission, and the following year he sent light through a fiber bundle half a meter long, well beyond what Lamm had achieved. Then van Heel encountered another complication. On a visit to Britain, fellow Dutch optical physicist Frits Zernike discovered that Hopkins and Kapany were also making fiber bundles. To establish his priority, van Heel quickly wrote a long article for the Dutch-language weekly *De Ingenieur* and a short letter to the British weekly *Nature*. He also airmailed a letter to O'Brien, alerting him to the planned publications. The Dutch weekly published the paper in its 12 June 1953 issue [9], but *Nature* uncharacteristically sat on the short letter for months. Neither mentions O'Brien, who evidently never replied to van Heel's letter.

Why O'Brien failed to reply is a mystery, and so is why *Nature* delayed publication of van Heel's letter until 2 January 1954 [10], when it appeared in the same issue as a longer paper that Hopkins and Kapany had submitted in November [11].

O'Brien was busy with other projects, including moving to head American Optical's new research laboratory in Southbridge, Massachusetts, in 1953. He never published on clad fibers, but he did apply for a patent through American Optical's lawyers in November 1954. The patent office duly granted the application [12], but it was overturned in court because of a blunder by the lawyers. With a year to file the patent after publication of the *De Ingenieur* paper, they interpreted the date 12/6/53 marked on O'Brien's copy as the American style with the month first, rather than the European style with the date first, and missed the deadline.

In 1954, as today, *Nature* was one of the world's best-read research journals, so the two papers collectively put fiber optics into the public eye. Yet neither Hopkins nor van Heel could secure funding for further development.

Things were different in America. A young South African gastroenterologist working at the University of Michigan named Basil Hirschowitz was excited by the idea of making a flexible fiber-optic endoscope. The Central Intelligence Agency picked up on an idea mentioned in van Heel's paper—that fiber bundles might make unbreakable image scramblers. And Kapany landed a research post at Rochester.

At Michigan, Hirschowitz teamed with his supervisor Marvin Pollard and optics professor C. Wilbur "Pete" Peters on the project in mid-1955. They hired Lawrence E. Curtiss, a physics student interested in medical instruments, to do the leg work. Hirschowitz did not know that Curtiss was just starting his sophomore year.

Curtiss ran into problems when he tested bare fibers that Hirschowitz had bought. Cleaning the fibers improved their light transmission, but every time he touched the fiber, transmission dropped about five percent. The mysterious loss came from fingerprint oils, which dry to leave a residue with a refractive index of 1.5, close enough to the glass index to spoil total internal reflection. Drawing their own fibers from glass rods with refractive index of 1.69 overcame that problem, but the bundled fibers scratched each other, again increasing losses.

Peters suggested applying a plastic or lacquer cladding, but that reduced light transmission. Curtiss suggested threading a high-index rod through a low-index tube and drawing the two into a clad fiber, but the older physicists said it would never work. For a few months he heeded their advice, and he and Peters made a three-foot-long bundle, which they described at an OSA meeting in Lake Placid, New York, in October 1956. But Curtiss still thought rod-in-tube fibers would work better. When Peters was away at a conference on 8 December 1956, Curtiss bought some tubes of soft glass from the chemistry supply office, put rods in them, and drew the clearest glass fibers that had yet been made.

Curtiss had been lucky. Drawing good rod-in-tube fibers requires very clean rod surfaces, and they had happened to buy fire-polished rods. Nonetheless, they had a breakthrough, and the project went into overdrive. Hirschowitz wasted no time applying for a patent, and by February the group had assembled the first fiber-optic endoscope.

Meanwhile, the CIA pressed American Optical to develop fiber-optic image scramblers for encoding and decoding secret documents. When O'Brien did not get the project going quickly enough, the CIA hired Will Hicks, a young physicist from Greenville, South Carolina, and sent him to build image scramblers for American Optical. Like the Michigan group, he tested plastic and glass cladding, but he took a different course and developed rigid bundles of fused fibers suitable for image scramblers.

Image scramblers turned out to have a fatal flaw—they always scrambled images in the same way, so an enemy who intercepted enough of the scrambled images could eventually work out the key. Hicks was the first to spot the flaw, but through a friend he also came up with a new use for the fused fiber bundle technology, as fiber optic faceplates to guide light between stages of an image intensifier.

Rigid or fused fiber bundles opened technological possibilities that were different from those of flexible bundles. Melting bundles of fibers together and stretching them made the light-guiding cores of the fibers thinner than the cores of isolated fibers, and groups of fused fibers could be stacked together and drawn again, to make them even thinner. Hicks noticed that fused bundles with the finest fibers showed odd colored patterns on their cut and polished ends. American Optical managers showed the odd pattern to Elias Snitzer when he interviewed for a job, and Snitzer recognized them as mode patterns, produced because the fibers had been drawn so thin that their cores were transmitting only a single optical mode. Snitzer got the job and became the first to describe single-mode transmission in an optical fiber [13]. Single-mode fibers would eventually become the backbone of the global fiber optic communications network.

Kapany took a different course at Rochester, writing a series of papers outlining the principles of fiber optics. First published in *Journal of the Optical Society of America*, they became the core of the field's first textbook. The 46 papers he published through 1966 accounted for 30% of the field's entire literature during the period, including reports on medical treatment.

Hirschowitz and Curtiss helped American Cystoscope Makers develop the first fiber optic endoscope in 1960. It quickly replaced earlier semi-rigid endoscopes because it was far more flexible and much safer to use, and it greatly expanded the use of endoscopy. American Optical and a spinoff company formed by Hicks in 1958, Mosaic Fabrications, developed fused fiber bundles into military and commercial products. Fused and flexible fibers soon found a range of applications, from reading punched computer cards and inspecting the innards of NASA's massive Saturn V rockets to decorative lamps. But none of them were transparent enough for communications.

Note: This essay based on material from [14].

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