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The Birth of Fiberoptics from "Light Guiding"

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Visual examination of and intervention in the urinary crannies, crevices, and cavities constitute the cornerstones of endourology. In this endeavor, adequate light transfer for proper visibility has been a perennial hurdle. From the early attempts at reflecting sunlight onto head mirrors to the use of candles and oil wick lamps to incandescent light bulbs, it has been an uphill journey until the advent of rod lenses and fiberoptic light transmission. Thanks to the fiberoptic principles, we now have near-natural quality and quantity of illumination for our endoscopic examinations. Yet this monumental invention began as a mere eye-catching gimmick or parlor trick more than 160 years ago.[1]

It was 1841. Daniel Colladon, a young professor of physics at the University of Geneva, was to demonstrate fluid flow through various holes of a cistern as part of his lecture on fluid dynamics. However, the lighting in the 19th Century lecture hall was inadequate for such demonstration. Colladon decided to illuminate his display by focusing sunlight with a lens onto the water tank. To his surprise, and the amusement of the assembled, the light spectacularly illuminated the water jets squirting out through the holes of the tank. The light rays trapped in the fluid by total internal reflection traveled along the curving arc of the water until the jets broke up in sparkles of light. It was thus demonstrated that light, which was believed to travel only in a straight line, could be made to follow a curve. The show was impressive, "one of the most beautiful and most curious experiments that one can perform in a course on optics," wrote Colladon, who coined the term "light guiding" for the physical phenomenon.[2]

Enamored of and amused by the display, Colladon popularized his show as part of his lecturing repertoire to the intelligentia. The light source was modified into an electric arc light instead of the sun by his contemporary August de la Rive. To establish his claim as the originator of "light guiding," Colladon submitted a report to *Comptes Rendu*, the official journal of the French Academy of Sciences. François Arago, the editor of the journal, recalled a recent demonstration of a similar phenomenon by Jacque Babinet in Paris and invited him also to write a report. Colladon and Babinet's separate papers were published in the same issue of *Comptes Rendu*.[2,3] Colladon happened to be a more eager promoter than Babinet, who was already an established academician and not so hungry for publicity. Babinet specialized in optics and extended the phenomenon of guiding light along bent glass rods. He mentioned in passing that the idea works well with glass shafts curved in whatever manner and could be used to illuminate the inside of the mouth, thereby hinting at what would evolve as fiberoptics.[3]

FIG. 1. Daniel Colladon

Although Babinet did not pursue light guiding experiments any further, Colladon's interest showed sporadic sparks of practical application of his trick. In 1853, he used light guiding as

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special effects in popular productions at the Paris Opéra. In a scene in *Faust*, he focused an arc lamp along a red glass tube filled with water to depict the devil Mephistopheles making a stream of fire flash.[4] Later, in 1884, the same phenomenon was used on a grander scale to illuminate the fountains at the International Health Exhibition of London.[1] At the Universal Exposition in Paris in 1889, the most spectacular illuminated fountain works bestowed recognition on Colladon as the father of the illuminated fountains.[5]

Famous British physicist John Tyndall replicated light guiding in a jet of water falling from a tank as part of his Friday evening lectures at the Royal Institute of London.[6] The demonstration was suggested to him by his mentor Michael Faraday, who appears to have seen it during his stay in Geneva 13 years earlier but, because of his failing memory, could not remember the name of Colladon or his associates who might have performed the show. Tyndall probably did not know and therefore failed to mention Colladon as the inventor of total internal reflection and light guiding. For many decades, the pioneers of fiberoptics development erroneously assigned the credit for light guiding phenomenon to the charismatic Tyndall instead of to Daniel Colladon.

Over the ensuing century, physicists carried the principle of internal reflection into other media, culminating in the fiberoptics revolution that swept the telecommunication field and medical diagnostics. Engineers assembled arrays of flexible glass fibers to guide light into inaccessible parts of the body. Earlier bare fibers with total internal reflection at a glass–air interface were covered with transparent cladding of lower refractive index to protect reflection surface from light contamination and reduce crosstalk between fibers, all leading to purer and more powerful light transmission.[1]

Incorporation of fiberoptics into flexible endoscopes started with the development of the flexible gastroscope in 1950 by a University of Michigan team led by Basil Hirschowitz, a gastroenterologist who tested the first prototype on himself.[7] In urology, small flexible ureteroscopes were proved to be feasible by Victor Marshall and associates in the early 1960s.[8] Over the decades, miniaturization of flexible endoscopes in urology aided by fiberoptics technology has probably reached its zenith. The safety, efficacy, and patient comfort of these endoscopes are beyond question. A fortuitous observation from a "parlor trick" has aided in a phenomenal advancement in our field of endourology. We owe the birth of fiberoptics to the keen observation of total internal reflection by Daniel Colladon and his perseverance in the exploitation of this phenomenon.

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