LASERS IN GASTROENTEROLOGY

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LASERS IN GASTROENTEROLOGY

Lasers in Medicine and Surgery Series

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Preface

Gastroenterologists have become like spelaeologists (potholers) probing into previously unexplored caverns and passageways. Anywhere accessible to a fibreoptic endoscope is accessible to a laser, and, in some cases, endoscopy is not necessary since the laser fibre can be guided by ultrasound control to the target tissue after percutaneous insertion. Following the almost simultaneous development of the flexible endoscope and the laser in the late 1950s, it took some 18 years for technology to allow the two to be used in conjunction. From early beginnings as a tool in the management of upper gastrointestinal bleeding, lasers have progressed in use to the ablation of tumour tissue and the disintegration of gall bladder and bile duct stones. The initial application of the Argon laser has evolved to the Nd-YAG laser in continuous wave form, to Q switching and pulsing of Nd-YAG lasers and latterly dye lasers, to metal vapour lasers and now there is the prospect of erbium and exzimer lasers.

No attempt has been made in this small volume to be exhaustively comprehensive, but I have brought together a group of international experts to cover the main areas of laser usage in gastroenterology and place in perspective the use of lasers in their currently applied fields. In addition, it is hoped to provide an insight into future areas of development in both clinical application and laser instrumentation as well as the need for ancillary equipment to deliver laser therapy. Finally, in the hope that smaller and therefore curable lesions might be treated, advances should also be anticipated in imaging techniques used to diagnose and define target areas.

Neville Krasner

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Part One

Introduction

1 A history of lasers

C. P. SWAIN and T. N. MILLS

> The thing that hath been, is that which shall be; and that which is done is that which shall be done and there is no new thing under the sun.
>
> Ecclesiastes 1, 8

The use of a beam of light delivered through a waveguide within a flexible endoscope to stop bleeding or recanalize an obstructing tumour seems so utterly new that it is tempting to forget that many historical threads may be traced in the development of this technology. The history of the laser and its application in medicine may be considered in its various phases from early antiquity to modern times.

1.1 The development of mirror and optical technology (early antiquity to sixteenth century)

Lasers could not have been developed without mirrors, optical technology using glass and an understanding of the rectilinear propagation and refraction of light. These elements are of great antiquity.[1–3]

The earliest surviving mirrors are probably those found in ancient Egyptian sites.[3] For example, a perfect mirror was found in the workers' quarters close to the pyramid of Sesostres (1900 BC) in the Valley of the Kings. Ancient writings record the use of these early mirrors made of polished metal, a striking example is found in Exodus 38, 8 (1200 BC): Belazeel, while preparing the ark and tabernacle, recast the looking glasses of women into a brass laver or ceremonial wash basin. The Winthrop mirror (c. sixth century BC)[4] is a beautiful glass inlaid Chinese bronze mirror with a high barium content in the glass. Mirrors were initially made of polished copper or bronze but by Roman times were made of speculum (the Latin word means mirror), a copper alloy rich in tin. Mirrors of glass were first produced in Venice at the beginning of the fourteenth century.[3] A polished plate of glass was placed on a smooth stone table, the glass was covered with a sheet of tinfoil and rubbed smooth, mercury was then poured on to form an amalgam with the tin. The high quality of these early glass mirrors can be judged from the quality of the image of the convex mirror which shows a miniscule back view of John Arnolfini and his wife in a famous painting by Van Eyck in the National Gallery in London. Amalgams of other metals in the manufacture of mirrors are described by sixteenth century craftsmen including lead, by Hans Sachs (1568) and antimony, by Branuccio (1540). Silvering of mirrors was first developed in 1840 using an ammoniacal solution of a silver salt such as silver nitrate to which carbonic acid and sugar candy had been added.[3]

A converging glass lens of rock crystal is said to have been found at Nineveh.[1] Aristophanes in the comedy of The Clouds (Act 2), produced in 429 BC, includes a conversation about fine transparent glass with which fires were kindled.[5] Glass technology was advanced by Roman times. There is evidence that the Romans had an array of lenses.[1, 2, 5, 6] Water-filled glass globes were used to start fires and possibly also for magnification work. A planar convex lens was recovered from Pompeii where it had been buried by volcanic eruption in 79 AD. Lenses for spectacles ground to correct refractive errors were probably first invented and manufactured in Northern Italy about 1286,[3] although their use seems to have also been considered by the great English mediaeval scientist Roger Bacon (1215–1249).[7]

The rectilinear propagation of light was known to the ancient Greeks,[8] as was the law of reflection which was described by Euclid (300 BC) in his book Catoptrix.[9] The apparent bending of objects partly immersed in water is mentioned in Plato's Republic.[10] Refraction was systematically studied by the great Alexandrian scientist Claudius Ptolemy (130 AD).[11] The scientific understanding of optics within the Graeco-Roman tradition was transmitted to mediaeval Europe through Arabic sources[2, 3, 6] which were translated into Latin, notably through Ibn al Haithan (Alhazan) (965–1039) whose writings also extended the understanding of the laws of refraction and the performance of spherical and parabolic mirrors.[12]

Various theories on the Nature of Light were suggested by Aristotle, Hero and others.[8] A view of light as an emission from the seen object was maintained by Pythagoreans and countered by Platonists who held that light was an emanation from the eye.[8] Avicenna (Ibn Sini) advanced a corpuscular theory of light in 1000 AD and suggested that light had a finite speed.[13]

1.2 The evolution of a modern understanding of the physical properties of light with the fusion of the corpuscular and wave theories of light in quantum theory of matter (seventeenth to twentieth centuries)

The true nature of light has been the subject of conjecture and scientific investigation for many centuries.[14–20] René Descartes (1596–1650) considered light to be a pressure transmitted through a perfectly elastic medium called the aether which fills all space and attributed the diversity of colours to rotary motions with different velocities of particles in this medium.[21] In the seventeenth century, some researchers, including Sir Isaac Newton (1642–1710), favoured a corpuscular theory which treated light as being made up of a stream of particles or corpuscles.[22] Others, of whom Robert Hooke (1635–1703)[23] and Christian Huygens (1629–1695)[24] were the principal proponents, preferred to consider light as a wave propagating through an all-pervading elastic medium they called the aether. Experimental evidence was available to support either theory.

The nature of colour was discovered by Newton in 1666 who observed that white light could be split into component colours by means of a prism and that each colour possesses a specific refrangibility. The difficulties which wave theory encountered in connection with the rectilinear propagation of light and of polarization (discovered by Huygens) seemed to Newton so decisive that he devoted himself to the development of a corpuscular or emission theory suggesting that light is propagated from a luminous body in the form of minute particles.

Fuelled by the considerable weight of Newton's opinion, yet contrary to his scientific philosophy, most scientists supported the corpuscular theory with tenacity and dogma, whilst the wave theory was all but stifled. This state of affairs persisted until 1802, when Thomas Young (1773–1829),[25] a physician at St George's Hospital, and a few years later the Frenchman Jean Fresnel (1788–1827),[26] revived the wave theory of light to explain the phenomena of diffraction, polarization and interference. Young suggested that light was a transverse wave, not a longitudinal wave; that is, the medium through which the wave propagated was disturbed in a direction perpendicular to rather than parallel to the direction of propagation.

The speed of light was first measured terrestrially by Armand Fizeau (1819–1886) in 1849 and by the late nineteenth century it was generally agreed to be about 300 000 km/s. Importantly its speed was found to be less in water than in air. Because Newton had predicted the reverse, this dealt what was thought to be the final blow to the corpuscular theory of light. The evidence now favoured the wave theory.

In 1867, James Clerk Maxwell (1831–1879),[27] who had been analysing data of experiments on electricity and magnetism, particularly those of Michael Faraday (1791–1867),[28] generated a set of equations which described exactly many of the observed properties of electricity and magnetism. An extraordinary result of this remarkable achievement was that the speed of propagation of a disturbance in an electromagnetic field, calculated using these equations, was exactly equal to the measured speed of light. Maxwell concluded that light was an electromagnetic wave whose propagation through the aether was determined solely by the electric and magnetic properties of the aether. The electromagnetic wave theory of light met with utter disbelief, until eight years after Maxwell's death, when Heinrich Hertz (1857–1891)[29] discharged an induction coil across a spark gap to set up oscillating electric and magnetic fields and generate long wavelength non-visible electromagnetic waves which could be reflected and refracted in exactly the same way as light.

So, light was an electromagnetic wave. But a number of problems remained. First, if it was a necessary assumption that the earth and other celestial bodies moved relative to a stationary aether, the speed of light measured in two different directions in space would be different. A famous experiment performed in 1887 by two Americans, Michelson (1853–1928) and Morley (1838–1931),[30] showed that this was not the case. The speed of light, which they were able to measure with very great precision using Michelson's interferometer,[31] was the same in all directions. This problem was resolved in 1905, when Albert Einstein (1879–1955) published his special theory of relativity.[32] He showed that electromagnetic waves were self-propagating: they had no need of an aether, and the problems arising from its proposed existence could be simply forgotten.[33]

The problems now remaining were concerned with the emission and absorption of light, which the wave theory of light was still unable to explain. For example, classical wave theory predicted that the intensity of radiation emitted by a 'black body' should increase with decreasing wavelength.[34] This would mean that as the wavelength decreased into the ultraviolet, the intensity of the radiation would become infinite. This 'violet catastrophe' was not in fact observed in practice. Max Planck (1858–1947),[35–37] who treated the black body as being made up of numerous oscillating fields radiating electromagnetic waves, showed that a satisfactory explanation could be obtained if the energies of the oscillators were restricted to only certain 'quantum' values. An understanding of the nature of light was to be greatly influenced by quantum theory. Planck proposed that an oscillating electric system does not impart its energy to the electromagnetic field in a continuous manner but in finite amounts, or 'quanta' $e = h\nu$, proportional to the frequency v of the light where $h = 6.55 \times 10^{-27}$ erg/s (Planck's constant). This proposition was in direct opposition to classical ideas. The use of Planck's constant h is probably the most important feature to distinguish modern physics from the old.[16, 38, 39]

Another puzzling phenomenon was observed by Hertz while studying the electrical discharge between two metal electrodes. He noticed that a spark was formed more readily when the electrodes were illuminated by ultraviolet light. Further study revealed that the ultraviolet light prompted the release of electrons from the metallic surface of the cathode. Contrary to expectation, the effect did not disappear when the intensity of the light was reduced to below a particular level. Even at low intensities, the effect persisted. Called the 'photoelectric effect', this phenomenon could not be explained by the wave theory of light.[40]

Building on the ideas originated by Max Planck, Einstein provided an explanation of the photoelectric effect.[40, 41] He treated light as being made up of discrete indivisible packets of energy, later to be called photons by G. N. Lewis in *Nature* (1926).[42] The energy of each photon was inversely proportional to the wavelength of the light, such that ultraviolet light, which is of a short wavelength, is made up of photons having a high energy. Although the intensity of a beam of ultraviolet light may be very low, the energy of each photon is by itself sufficient to knock an electron off the metallic surface and reduce the voltage required to initiate a spark. It was for his explanation of the photoelectric effect and his application of quantum theory to light,[43] rather than his formulation of the special and general theories of relativity, that Einstein was awarded the Nobel Prize for Physics in 1921.

The concept of the photon, whereby light takes the form of both a particle and a wave, formed the basis of an entirely new branch of physics called the quantum theory of matter. The quantum theory shows that particle and wave are in fact different manifestations of the same thing, and, as stated by Einstein, that mass and energy are equivalent. The wavelength of radiation associated with a particle is inversely proportional to its momentum and so only subatomic particles, of which the photon is one, exhibit detectable wave-like properties.

Concurrent with these studies of the nature of light, studies of the submicroscopic world of the atom were yielding insights that were a necessary precondition to the development of the laser. Faruenhofer (1787–1826)[44] and others before him had noticed that the wavelength of light emitted or absorbed by a particular element was confined to a number of narrow bands or spectral lines peculiar to that element. Rutherford (1871–1937)[45] had modelled the atom along the lines of our