FCA Part 1 Refresher Course 2017

Endoscopic Airway Equipment

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Introduction

Safe, reliable airway management is integral to the practice of anaesthesia. While some procedures may be accomplished without advanced instrumentation of the airway, there are many in which the ability to accurately position endotracheal and endobronchial tubes, bronchial blockers, dilators and other devices is crucial to success, and ultimately, patient outcomes. The steady growth and refinement of endoscopes used to see within the airway has developed from simple tubes and reflected light-sources to sophisticated hybrid devices using fibre-optics and integrated video camera systems. A basic understanding of the physical properties that underlie the construction and function of these devices is essential to proper use and care.

These notes aim to give a brief introduction to the important principles, and a broad overview of the main types of endoscopic airway equipment in use. More information, training materials and video tutorials can be found on the open-access airway education web site, www.openairway.org. Specific queries can be directed to ross.hofmeyr@uct.ac.za

Inclusion of images or mention of specific products by name in these notes is for the purposes of discussion and is not an endorsement of the product.

Basic principles of conventional optics

Optics is that branch of physics which describes the characteristics and behaviour of light, instruments that use, detect or manipulate light, and its interactions with other forms of matter. Conventionally, it refers to visible, infrared and ultraviolet light, but as light is a form of electromagnetic wave, it has implications for other forms such as x-rays, radio and microwaves.

Conventional *geometric optics* describe the phenomena that can be accounted for using the classical electromagnetic ray form of light, which presumes travel in straight lines and reflection or refraction when meeting or passing through surfaces. Wave and particle effects such as interference and diffraction are described by the more comprehensive *physical* and *quantum optics,* but are largely beyond the scope of these notes.

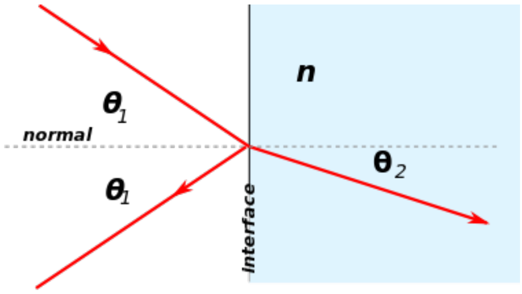

Figure 1. Geometry of reflection and refraction.

The fundamental principles of geometric optics are the laws of **reflection** and **refraction**. Angles of incidence, reflection and refraction are always measured from the **normal**, which is perfectly perpendicular to the interface. When a ray of light meets the interface between two transparent materials, it is split into reflected and refracted rays, so that:

> The reflected ray lies in the plane of incidence, and the angle of reflection equals the angle of incidence (**Law of Reflection)**
>
> The refracted ray lies in the plane of incidence, and the sine of the angle of refraction divided by the sine of the angle of incidence is a constant for any two materials and a given wavelength of light. (**Law of Refraction)**

This can also be expressed as **Snell's Law**, which describes the angles from normal for a light ray traversing from a medium with refractive index of n_1 to a medium with index n_2:

$$n_1 \sin \theta_1 = n_2 \sin \theta_2$$

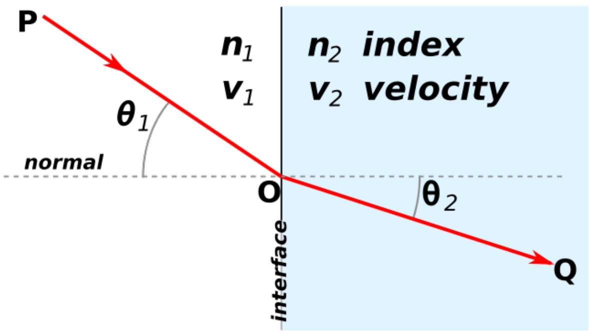

Figure 2. Snell's Law of refraction.

The velocity *v* of light in a transparent medium is determined by the nature of the medium, but is always less than the speed of light through a vacuum. The refractive index *n* for any given medium is therefore calculated as

$$n = c/v$$

where *c* is the speed of light through a vacuum. Where there is a marked difference between the indexes of refraction from one medium to another (such as between glass and air), Snell's law predicts that there is no θ_2 when θ_1 is sufficiently large. In other words, when the angle of incidence is sufficiently far from the normal, no light is refracted, and **total internal reflection** occurs. This is the fundamental principle of the function of fibreoptics (see below).

Lenses are devices which cause light rays to converge or diverge through refraction. Converging lenses focus incoming parallel rays onto a spot on *focal length* from the lens, on the opposite side. Diverging lenses spread the incoming parallel rays in such a way that they appear to have originated at a position one focal length on the same side as the origin.

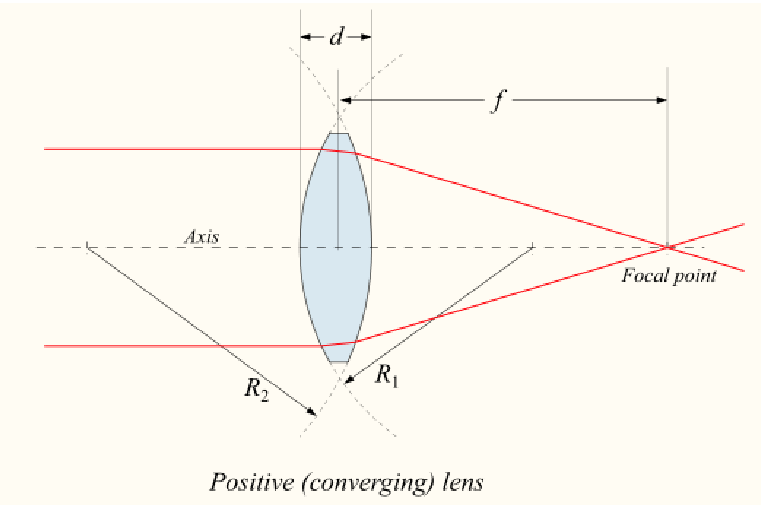

Figure 3. Converging lens. Image: DrBob, creative commons.

Several types of indirect laryngoscope (whereby an image of the vocal cords is produced without a direct visual axis) make used of a combination of lenses, mirrors and/or prisms. Examples include the TruView and Airtraq optical laryngoscopes.

Principles of fibreoptics

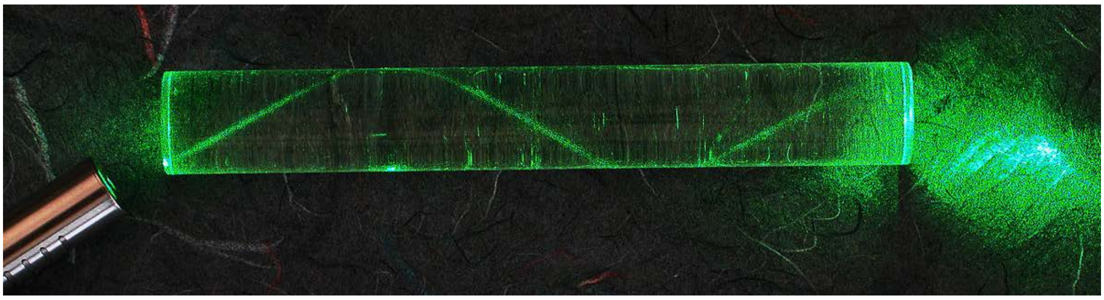

Figure 4. A laser passing down a Perspex rod illustrating the principle of total internal reflection of light in an optical fibre. Source: Wikipedia (User Timwether, creative commons license).

Optical fibres are flexible structures created by sequentially drawing transparent glass or plastic into a very fine diameter, often comparable to or thinner than a single human hair. Using the principle of total internal reflection, they allow transmission of light from one end to the other, potentially over long distances, with minimal loss of intensity. This is referred to as acting as a waveguide. Often, cladding material with a lower index of refraction is used around the optical fibre to further increase efficiency. They have wide-ranging uses in illumination, imaging, sensing and communications.

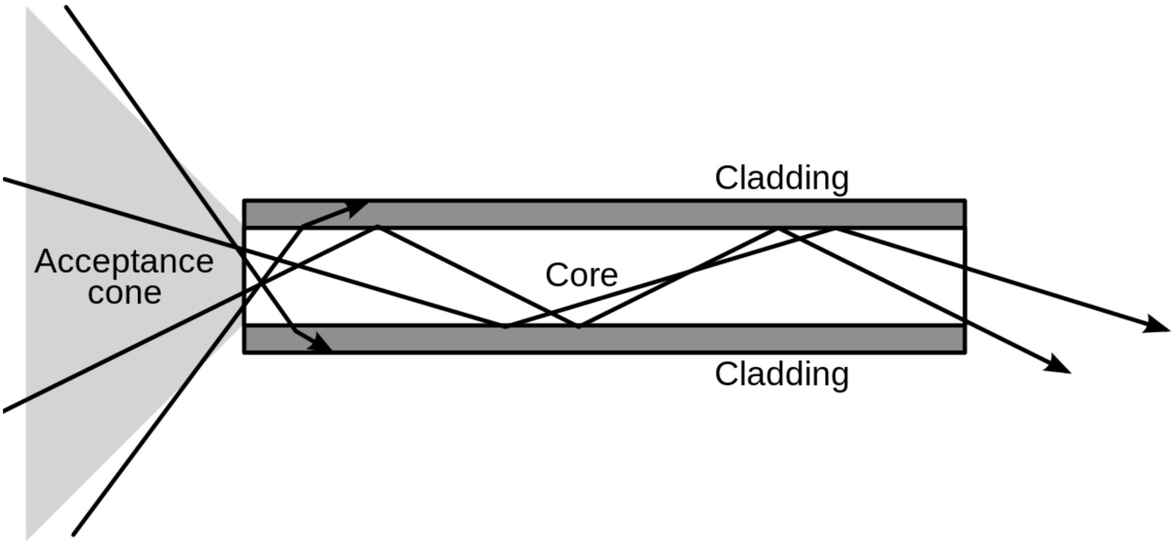

Figure 5. Schematic diagram of an optical fibre. Source: Wikipedia, public domain.

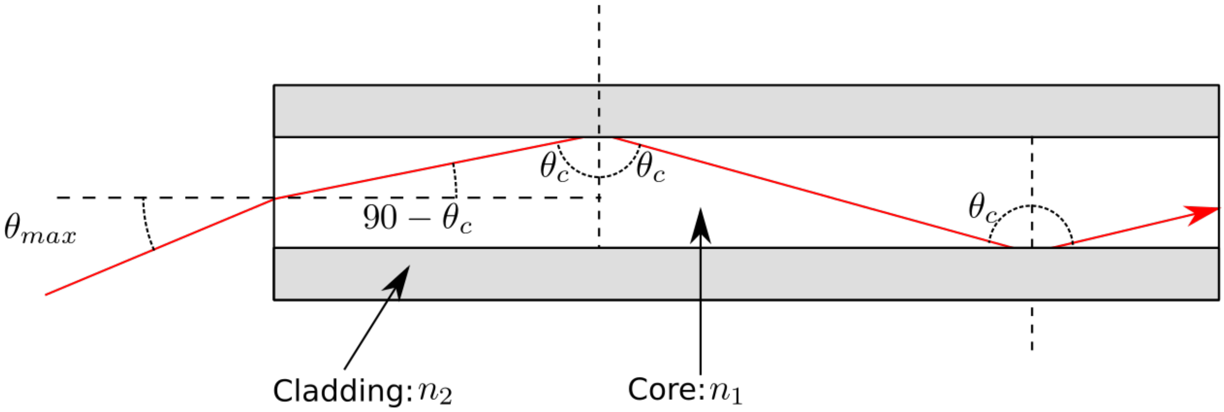

Figure 6. Schematic diagram of an optical fibre, showing the numerical aperture. Light undergoes total internal reflection due to Snell's Law. Source: Wikipedia, User A1 (English Wikipedia, creative commons license).

In medical endoscopes, optical fibre bundles (frequently consisting of tens of thousands of individual fibres) are used both to provide illumination and to produce an image. *Non-coherent* fibre bundles convey light from a light source distant from the patient to the end of the scope, thereby avoiding having a bulb at the scope's tip, which would produce heat and can cause burns. To convey an image, *coherent* bundles (where the fibres maintain their same perfect position parallel to each other from one end of the scope to the other) are used. An objective lens at the tip of the endoscope is used to focus the image on the fibre bundle, and an eyepiece at the user's end allows viewing the image.

Optical fibres allow for the creation of flexible endoscopes, and are used in some types of rigid endoscope for either light conduction, or both light and image conduction. A fibreoptic image is easily identifiable by the 'pixelated' appearance, as each individual 'pixel' is an individual fibre. Due to the very fine nature of optical fibres, however, they are susceptible to breaking through tight bends, hard knocks and crushing. Individual broken fibres can be seen in the image as black 'dead' spots. As the number of broken fibres increases, the scope eventually becomes unusable.

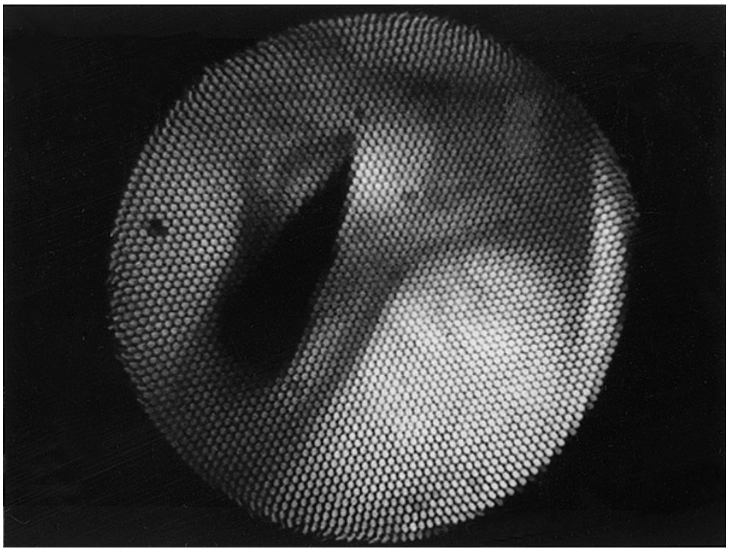

Figure 7. Fibreoptic image, showing typical honeycomb appearance and several 'dead' fibres.
Image: Dr Takayuki Kitamura.

Video camera and display integration into endoscopes

The value of performing endoscopy is greatly magnified if the image can be enlarged, displayed on a screen to enable multiple simultaneous viewers, and recorded for documentation, teaching and medicolegal purposes. The initial method to achieve this was to mount a still or video camera onto the eyepiece of an optical scope, and link the camera to a display and/or video recorder. Using modern rod lens telescopes in combination with a high definition (HD) camera, very high quality images can be recorded and displayed. One downside to this system, however, is that the weight of the camera can make holding and manipulating the endoscope more difficult and tiring.

Using an HD camera with a flexible fibreoptic scope is less effective, as the resolution is limited by the density of the fibre bundles themselves. This is often visible as a prominent 'honeycomb' pattern on the screen, which can make viewing difficult. To counter the honeycomb effect, slightly defocussing the scope, or the use of advanced imaging filters which interpolate between pixels can be used.

An alternate approach is to completely replace the optical fibres in flexible endoscopes with a digital video system. The advent of very small video camera sensors – and rapid improvement in their quality combined with reduction in cost, largely fuelled by the digital camera and mobile phone industries – has made these 'chip-in-tip' endoscopes increasingly common. The light source and non-coherent fibre bundles are also replaced by one or more light-emitting diodes (LEDs) at the end of the scope, which makes flexible video endoscopes lighter, more robust, and either thinner in diameter, or the same diameter with a larger working channel.

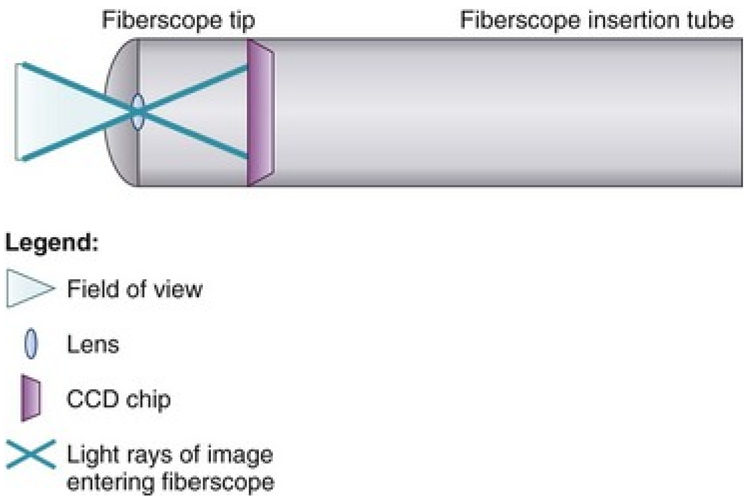

Figure 8. Schematic representation of a flexible video endoscope with 'chip-in-tip' CCD camera.

The original video chips were of the CCD (charge-coupled device) design. A thin silicon wafer is divided into a geometric array of light-sensitive regions (picture elements, or 'pixels') that locally store a charge dependent on the degree of light exposure. After exposure, the charge accumulated by each pixel is transferred across the array in sequence, creating a digital signal which encodes the image. This has been likened to an array of buckets collecting rain:

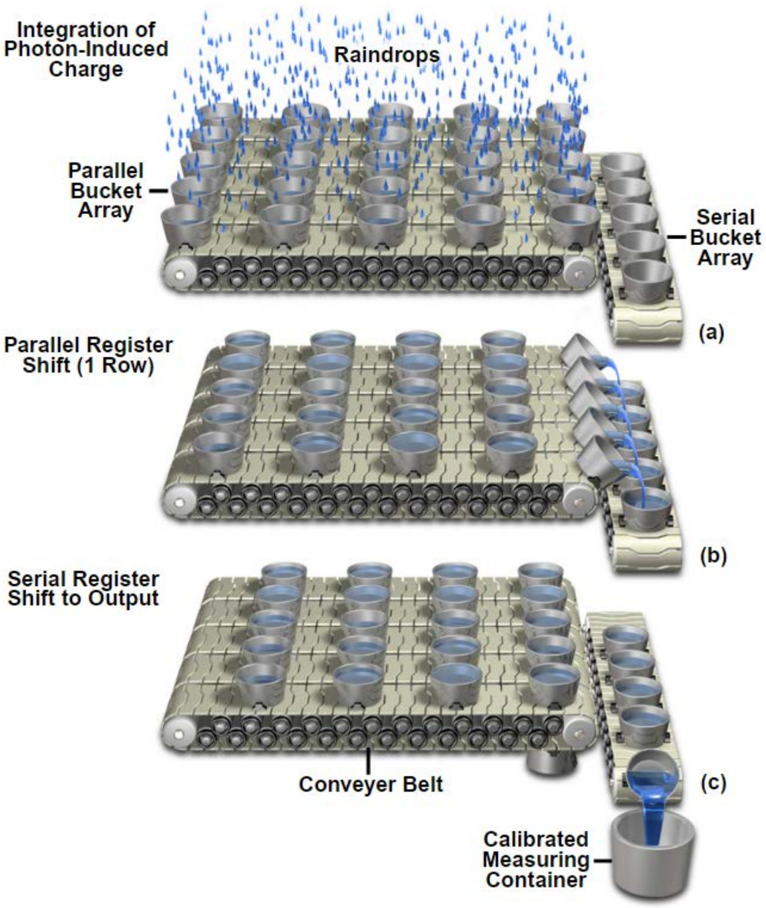

Figure 9. CCD 'Bucket Brigade' analogy: Individual pixels (buckets) collect incoming photons (raindrops) in the form of electrical charge. This is then transferred across the array in orderly steps, and recorded sequentially into a gigital signal.

A second type of digital image chip is the CMOS (complementary metal-oxide semiconductor) sensor, which employs a similar array architecture but allows multi-channel recording from the matrix, greatly increasing image capture speed. CCD sensors are more sensitive to light than CMOS, and therefore produce images with less 'noise' at the same light intensity than CMOS. However, in the light-abundant environment of airway endoscopy, this is much less of a disadvantage. CMOS, however, are more power-efficient and can be produced at much lower cost. Steady improvements in CMOS sensor quality has led to their domination of the camera chip market, and most modern video endoscopes use a CMOS chip.

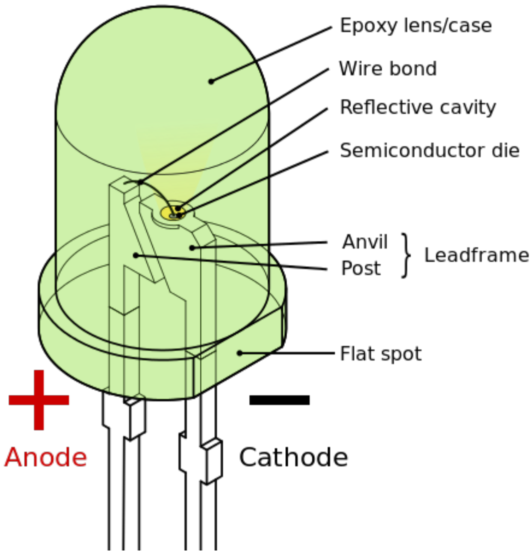

Figure 10. Schematic diagram of a light-emitting diode

Light-emitting diodes (LEDs) are electroluminescent light sources, in which the interface between two semiconductor materials produces photons when subjected to a suitable voltage. They have multiple advantages for the use in endoscopes of all types when compared to incandescent and fibreoptic light sources: small size (less than 1 mm^2, low power consumption, long lifetime (of measured in tens of thousands of hours), physical robustness, and little or no heat production. Although the advent of fibreoptic light guides ushered in the concept of 'cold light sources', only the incorporation of LEDs into endoscopes has truly achieved this goal.

Continually improvement in quality and reduction in both cost and size of both image sensor chips and LEDs has led to an explosion in their use in both flexible endoscopes and video laryngoscopes.

Types of equipment for airway endoscopy

Devices used for airway endoscopy can be classified by the site of desired use (eg. laryngoscopes, bronchoscopes), the method used to transmit an image (eg. direct, standard optics, fibreoptic or video), and specific properties of the design (eg. rigid or flexible). No single system of classification exists for all the available devices. Furthermore, in specific circumstances, equipment from disciplines outside of anaesthesia is often used in complex airway procedures (for instance, rigid telescopes or suspension laryngoscopes). In these notes, various types of direct laryngoscope are not discussed, as this information is broadly available elsewhere.

Figure 11. A structural and functional classification of indirect laryngoscopic devices

Laryngoscopes

Optical laryngoscopes

Optical laryngoscopes use lenses, prisms and/or mirrors to convey the image to an eyepiece, creating an indirect view of the larynx, but allowing guided intubation. They often have the advantage of being either low cost and disposable, or fairly compact and robust. All of the current devices on the market can have some form of camera connected to the eyepiece to allow display on a screen, forming a hybrid optical/video device.


Figure 12(a) and (b). Airtraq optical laryngoscope, showing use and internal construction of lenses, with electrical wires for the LED light source. Note the channelled blade shape. Images: Manufacturer.

Figure 13. Truview optical laryngoscope. Image: Manufacturer

Video laryngoscopes

The number of video laryngoscope (VL) devices on the market has been rapidly increasing. All use some form of CMOS or CCD camera chip and LED light source, and display the image either on a separate screen or display mounted on the handle. Both disposable and reusable blade devices exist. VLs can be classified according to their blade shape into three groups, which dictates their strengths, weaknesses and particular utility in different airway situations:

- Hyperangulated blades, such as the classical Glidescope blade or CMAC D-blade
- Traditional Macintosh or Miller shaped blades
- Channelled blades, such as the Pentax AWS or King Vision VL

Figure 14. A set of video laryngoscopes, showing hyperangulated and conventional Macintosh and Miller blade shapes with a separate video display. Image: Manufacturer

Figure 15. King Vision VL with channelled blades and display mounted on hande.

Intubating endoscopes

Rigid intubating endoscopes

Also known as optical or video stylets, these devices are preloaded with an endotracheal tube and provide a 'through the tube' view during intubation. They are designed to be used alone, or in conjunction with a laryngoscope (known as *dual endoscopy).* Common examples include the Bonfils, Shikani and Levitan optical stylets, and the Clarus and CMAC-VS video stylets. The optical stylets use fibreoptic bundles for illumination and image creation, but are much more robust than flexible fibreoptic scopes due to their rigid construction. Despite this, they are manufactured in sizes down to an external diameter of 2 mm, allowing paediatric tubes of as small as 2.5 mm ID to be used. These devices have the further advantage in very soiled airways of being able to be used as a lightwand if intubation under vision is not possible.

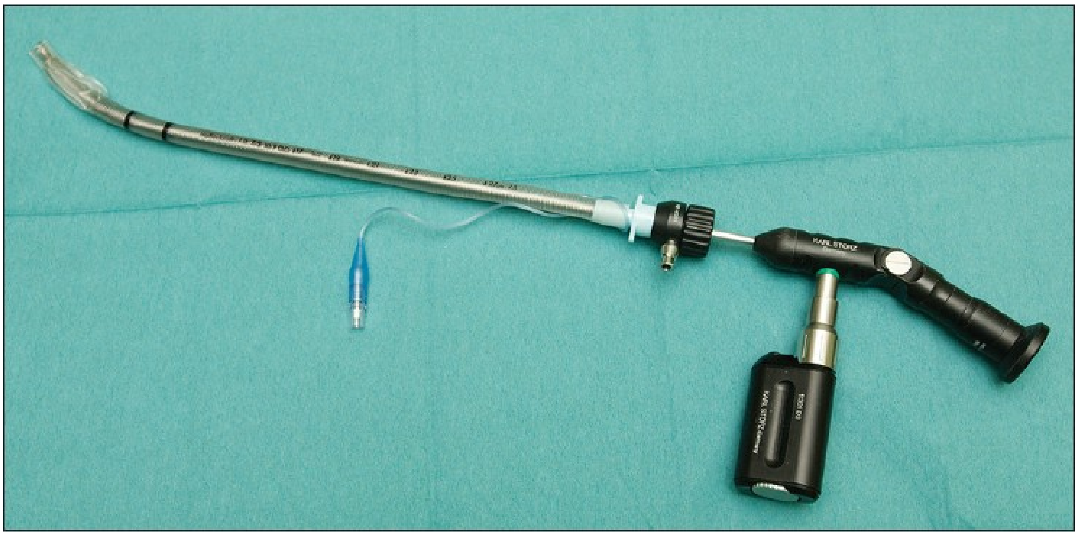

Figure 16. Bonfils rigid intubating endoscope with preloaded endotracheal tube and batter light source.

Flexible intubating endoscopes

Flexible intubating endoscopes are either fibreoptic or 'chip-in-tip' video endoscopes, and are designed for awake intubation of very challenging airways. Functionally, they bear very close resemblance to flexible bronchoscopes (see below), and are often used interchangeably. Modern models have an interface between the control body and insertion tube (or an additional accessory) to securely hold a pre-loaded endotracheal tube during endoscopy for intubation. Typically, the minimum internal diameter of the ETT should be no less than 1 mm greater than diameter of the scope.

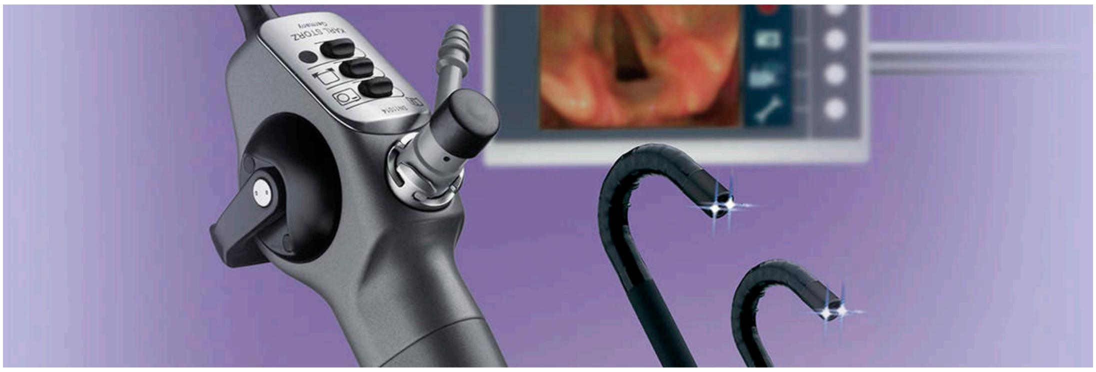

Figure 17. Control body and flexible tip of a flexible intubating video endoscope (FIVE)

Bronchoscopes

Rigid bronchoscopes

Essentially a straight metal tube with connections to allow passage of light, rigid telescopes and operating instruments, rigid bronchoscopes can be used with the naked eye (with a fibreoptic light source connected directly to the scope with a prism) or with a telescopic camera. They are useful to gain access to the airway when swelling or external compression causes collapse or obstruction, and offer a large diameter working area for surgical tasks and removal of foreign bodies. Rigid tracheoscopes are a slightly shorter variant without side holes, which allows ventilation through the scope while working.

Figure 18. Comprehensive system for rigid brinchoscopy, including rigid telescope, several bronchoscopes, graspers, and attachments for jet and conventional ventilation as well as light delivery.

Flexible bronchoscopes

Practically speaking, there are trivial differences between flexible intubating endoscopes and flexible bronchoscopes. The former are usually slightly (~5 cm) shorter and slimmer (5.0 – 5.5 mm external diameter), and the latter place larger emphasis on having a larger working channel for graspers and biopsy forceps at the expense of a slight increase in diameter (5.8 – 6.3 mm). 'Paediatic' versions of both scope exist, with external diameters of usually 3.0 – 4.0 mm. However, taking into account the implications of scope diameter for endotracheal tube size selection, they function perfectly well for intubation.

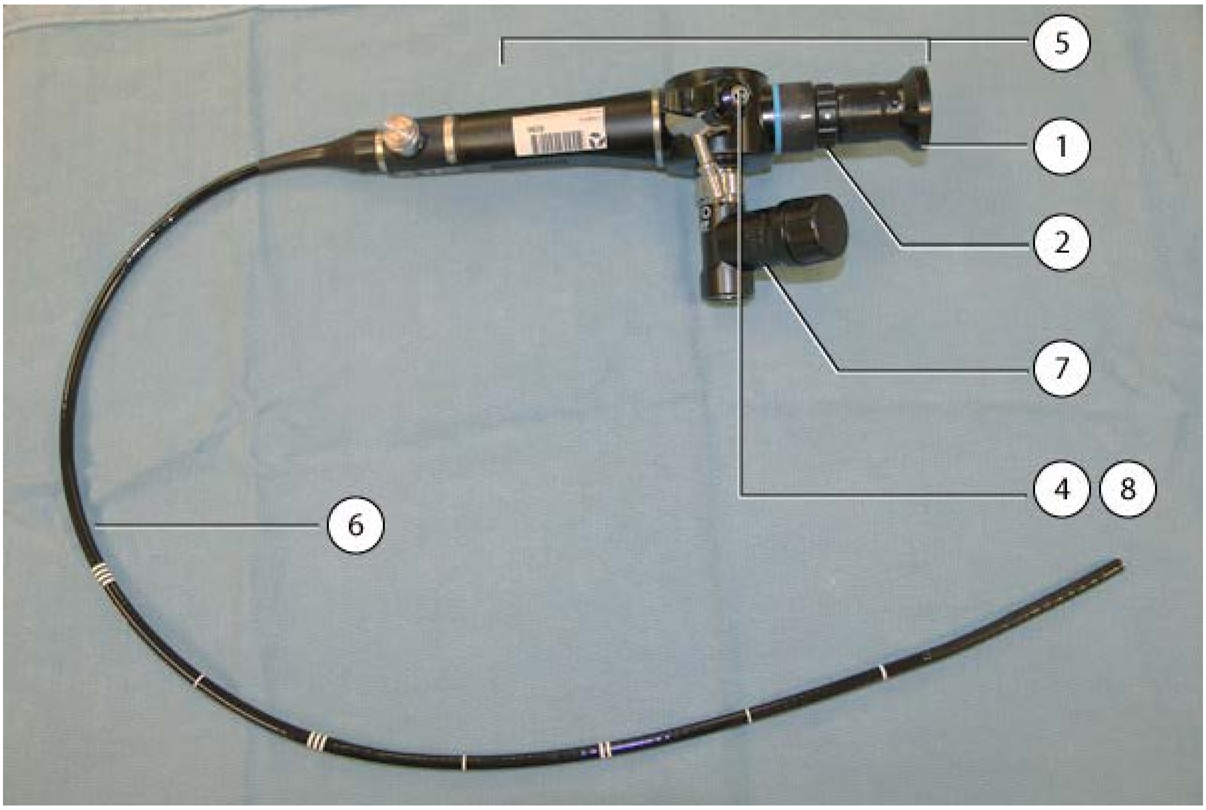

Figure 19. Flexible fibreoptic bronchoscope. Parts: 1) Eyepiece 2) Focus ring 3) Control lever 4) Working channel port 5) Control body 6) Insertion cord 7) Light source 8) Suction valve/port. Image: Toronto General Hospital Department of Anaesthesia online learning

Figure 20. A portable flexible video bronchoscope with integrated display. Image: Manufacturer

Operative telescopes

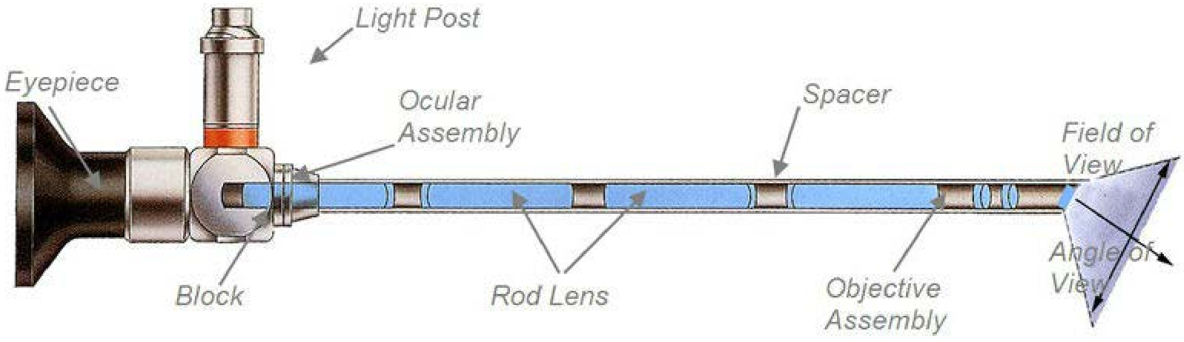

Figure 21. Typical construction of an operative endoscopic telescope, utilising a rod lens design. Image courtesy Fuzhou Alpha Optics.

Originally, endoscopic telescopes had a traditional lens design, which featured small lenses separated by large air gaps. Physicist Harold Hopkins realised, however, that an alternate design in which the lenses where long rods separated by small airspaces was more efficient, and did not require structures to hold the lenses in place, increasing their size and optical efficiency. This increased the image quality, brightness, and field of vision, while at the same time making the endoscope more robust. After patenting his design in 1959, he was approached by the German optical instrument maker, Herr. Karl Storz, to incorporate the design into his endoscopes. This was a turning point for both men; Hopkins became famous for the design (amongst others), and Storz grew his company into the foremost manufacturer of rigid endoscopes in the world. Most modern operative telescopes now use this design, which can be used to create scopes with diameters as small as 1.2 mm while still producing images far better than those achieved with today's chip-in-tip sensors.

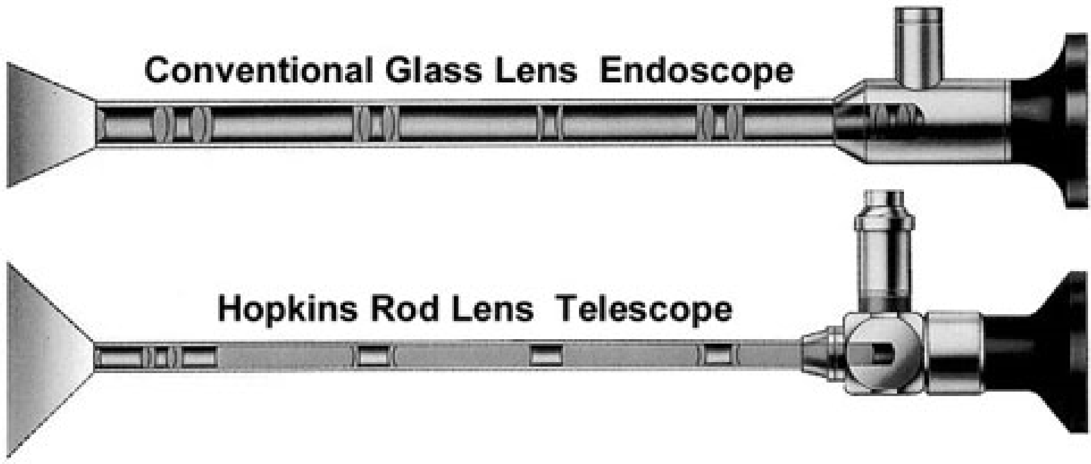

Figure 22. Conventional operative telescope (endoscope) in comparison with the Hopkins 'rod lens' design. Image courtesy of Karl Storz GmBH.

The Future

Clearly, endoscopic airway devices are continuing to evolve, and with them, our surgical and anaesthetic techniques. Patients previously deemed very difficult airways for whom only an awake fibreoptic intubation was advocated are now routinely intubated with asleep video laryngoscopy, and procedures such as tracheal dilatation which were only performed with rigid bronchoscopes and bougies are now being achieved as flexible endoscopic day cases through a supraglottic airway. Just as many procedures in cardiac surgery are not achievable without an ‘echo anaesthetist’ who can provide intraoperative echocardiographic views, so too are procedures in ENT and thoracic surgery beginning to require an ‘interventional anaesthetist’ who can both control and image the airway. However, quantifying the contribution of these novel and advanced techniques to a wide base of patient outcomes remains a challenge. It is incumbent upon the individual practitioner to become highly skilled with the tools at their disposal, and to recognise the relative strengths and weaknesses of each device in each situation.