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Project Report

Fiber Optics in Medicine

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**Abstract:**
Fiber optics have become very important in medical diagnoses in this modern era of science and technology. Due to the fact that many instruments are bulky and difficult to use, optical fibers that are small in diameter are used as guides to transmit beams inside the body for the purpose of both diagnoses and treatment. This paper will explore the use of fibers in endoscopic imaging that is internal imaging of the human body. The ability to see inside the body without cutting is what makes this technology very important and interesting.

**Introduction:**
I have always been interested in medicine and the use of technology to make medicine a more efficient practice. The ability of professional doctors to see what is really going on in the human body helps to answer questions that will otherwise be answered by guesswork. Fibers are especially interesting because they are bendable and therefore can navigate through the complex topology of our internal organs with causing much damage. They can also reach where solid objects cannot. The images captured by these optical devices are very accurate and are in most cases three-dimensional. This gives you a real picture of our internal organs and hence ability to diagnose anything that is wrong.

**Content:**

**Principles**
Optical fibers make use of the principles of light to transmit light through a very small thin flexible tube. The main principle used is total internal reflection. When light travels from air into water or glass a small fraction is reflected back into the air, the rest is transmitted through the medium. If light is sent from a glass to air at an angle of about 45 degrees or more with respect to the normal, the light is totally reflected back in to the glass. This is known as total internal reflection. If we replace the glass with a thin transparent, flexible glass tube also known as an optical fiber, light can be transmitted through it by internal reflections even if the fiber is bent.

The schematic below shows how light is transmitted through an optical fiber.
First let me describe how the optical fiber components are configured. Its structure consists of an inner rod (central core) and outer tube (cladding). The core has a higher index of refraction than the cladding. Below is a diagram of the structure of a typical fiber.

A fiber that has both a core and a cladding is called a clad fiber and if it has just a core and air instead of a cladding then it is known as an unclad fiber. To calculate the maximum angle at which total internal reflection occurs we must consider the Numerical Aperture (NA). The NA is therefore the maximum cone of transmittable light. It depends on the core diameter and the indices of refraction $n_1$ and $n_2$. Consider the following figure.
This value can be found by the following formula.

$$NA = n_0 \sin \alpha_{\text{max}}$$

This formula can be approximated to

$$\Delta = (n_1 - n_2)/ n_1$$

$$n_1 < n_2$$

Fig 1 is a cross section of a cylinder. Any ray of light impinging on the end with an angle $\alpha_0 < 33$ degrees will be transmitted through the rod or fiber by total internal reflection. There is a whole cone of rays with identical angles and behave identically. This is true if the rays are transmitted through the fiber. If rays are incident at an angle greater than 33 degrees, they are refracted into the cladding layer and the air. The angle of the cone is called the acceptance angle. Below is a figure showing the acceptance cone of an optical fiber.
Fig 5

**Travel of light through the fiber**

Light rays travel through the fiber by totally reflecting several times and finally emerging at the end of the fiber. Considering fig 1, the distance traveled by ray between two consecutive reflections is given by

\[ L_1 = \frac{d}{\tan \alpha} \]

If the total length of the fiber is \( L \), then the number of total internal reflections in the fiber is given by

\[ N_1 = \frac{L}{L_1} = \frac{L}{\frac{d}{\tan \alpha}} = \frac{L}{d} \tan \alpha \]

The main purpose of the optical fiber is to conduct light regardless of whether the fiber is bent or straight. Also high reflectance is needed in the fiber for maximum light transmission since intensity of the light decreases due to reflections.

**Fiber bundles**

A fiber bundle is made up of tens of thousands of fibers inserted in a plastic tube. These are used in applications to image transmission and illumination. Bundles in which the fibers are systematically ordered are called ordered bundles and are used for image transmission. Bundles that are not ordered are called light guides and are used for illumination. Both types made it possible to manufacture imaging fiberscopes and later medical endoscopes.

Non-ordered bundles are used by physicians to illuminate an area inside the body not easily accessible. The fibers are used to transmit light from a light source to the required location. The bundle is flexible and has large area. They are glued together at the ends and the rest of their length free. This prevents the fibers escaping the bundle. The bundle is still flexible and is protected by plastic. The light needed as the source is usually light from high-intensity lamps such as high-pressure Xenon, quartz halogen, or mercury lamps. This light is focused on the bundle end by a simple lens system. Heating can be a problem in such systems but this can be handled by cooling and filtering out some of the infra red light with a heat-rejecting optical fiber. Typical light guides fibers have a
typical core diameter of 15-50\(\mu\)m and an outer diameter of 20-60\(\mu\)m. Laser light sources are not used for imaging because an illuminated surface looks unevenly illuminated because of speckle. This is caused by interference effects resulting from temporal coherence of the light.

Ordered bundles consist of accurately aligned fibers in a bundle so that the order of the fibers in one end is identical to the order in the other end. It is also called the coherent bundle. If an image is projected on to one end of the bundle, each individual fiber transmits the light impinging on it and the ordered array transmits and replicates the exact image at the other end. These kinds of bundles are part of the building blocks of fiberscopes and endoscopes. The individual fibers in the bundle must be clad fibers so that light cannot leak from one fiber to neighboring fibers. If this happens it causes the poor quality of light to be transmitted hence poor pictures. Figure 6 bellow shows and example of ordered and non-ordered bundles.

Fig 6

Figure 7 shows a picture of an ordered bundle.

Fig 7
Figure 8 shows a schematic drawing of a fiberscope. An objective lens is attached to the distal end of the ordered bundle. An image of the object is formed on the distal end face of the ordered bundle and is transmitted through the bundle to the proximal end. Another compound lens system (eye piece) is used to facilitate viewing of the image at the proximal end. A photographic camera can also be connected or a television (video) camera can also be connected to the proximal end of the bundle with a special adapter. The image is then recorded with film or magnetic tape. The focusing of the fiberscope can be adjusted by changing the distance between the objective lens and the fiber bundle. The optical set up is often designed to provide a fixed focus with large depth of focus.

**Endoscopes**

The endoscope is a medical system that makes use of fiberscopes for imaging inside the body. It contains several ancillary channels that are used for the introduction of thin mechanical tools or for the introduction of liquids inside the body. Below is a figure of a modern gastroscope.
It is the simplest example of the endoscope. It consists of three major parts. The insertion suction tube, with a distal end; the hand piece (control box) section with control knobs and other functions; and the connecting cable section with the lightguide tubes connecting air and water supplies.

**The distal end**
This houses the distal tips of several of the optical and mechanical components. These include a tip of one or two light guides, which provide illumination; the distal tip of the imaging bundle; and a miniature objective lens attached to the tip of the bundle. A thin, flat protective window that is easy to clean may cover the tip to protect it from contamination by blood. The distal end is often immersed in fluids, secretions or blood, which tend to affect viewing. A flushing port is supplied through which a stream of water can be sprayed on the tip to keep it clean. Different objective lenses are used to give different fields of view. The distal end may also contain one or many outlets that are used for irrigation, aspiration, suction, or insertion of thin instruments. In some cases a bridge that is raised when the instrument is introduced through the endoscope protects the instrument outlet. The Cross section of the distal end is shown in fig 10.
Flexible shaft
This holds the light guide, imaging bundle and the ancillary tubes together. It is connected to one side of the distal end and at the other side to the proximal end. The shaft is constructed of steel mesh and can be strengthened further by a steel spiral. This stiffens the endoscope, gives it mechanical support and protects the delicate optical and mechanical components. It also enables the physician control the endoscope mechanically. A plastic jacket that is biologically inert and that forms a hermetic seal covers the flexible shaft. It protects the inner parts of the endoscope from interaction with water and blood. The flexing and angulation mechanisms are shown in fig 11.

The proximal End
This includes viewing optics, controls and several ports. These are often housed in a hand piece held by the physician. All the control knobs, buttons, levers and photographic equipment are connected to this hand piece.

The optical system of the endoscope may have a fixed focus arrangement. All objects within a certain distance from the tip will be seen clearly. Others have a focusing unit in addition to the eyepiece. Photographic equipment can also be attached to the eyepiece using special adapters, in order to help recording of a whole sequence of events.
The distal end is connected by wires to knobs that are located in the proximal handpiece. This controls the movement of the tip.

Several ports serve different purposes. Some are for the passage of fluids such as saline solution or drugs and others are for pressurized gases such as air or CO2. There are ports for aspiration of gas or the suction or liquids. Surgical instruments and auxiliary optical fibers can be introduced through the operating port.

cables
Different cables connect the endoscope to the supply system. The proximal end of the light guide is connected to the light source. Air insufflation and aspiration tubes are connected to an air pump and the liquid ports are connected to liquid reservoirs or suction subsystems.

Supply system
This includes a light source essential for illumination of photography and optimal vision. Quartz halogen lamps and mercury and xenon arc lamps are used as light sources. The supply system also contains a pump that provides pressurized air for the insufflation tube. The ability to pump out gases and debris is vital in endoscopic laser surgery. Fig 12 a and b shows a picture of a modern endoscope and a picture of gastric cancer taken by an endoscope.

Fig 12a
Endoscopic imaging - Advances

In the early days of fiberoptic endoscopy, the quality of the imaging bundles was not good enough. One solution involved attaching a miniature camera to the distal end of the endoscope. The imaging bundle was used only to locate a desired area. A light guide provides illumination and still photographs were taken with the camera. This has changed with the development of higher-resolution imaging bundles. In the early days of fiberoptic endoscopy, the quality of the imaging bundles was not good enough. One solution involved attaching a miniature camera to the distal end of the endoscope. The imaging bundle was used only to locate a desired area. A light guide provides illumination and still photographs were taken with the camera. This has changed with the development of higher-resolution imaging bundles. During the last few years, there has been tremendous progress in the development of small imaging devices. Of such device is based on charge-coupled devices (CCDs). It is manufactured by microfabrication techniques. It consists of an array of tens of thousands of light-sensitive elements and some electronic circuits needed to operate the device on a small Silicon chip whose area is less than 1 cm². This device is placed on the distal end tips replacing the imaging bundles. The non-ordered bundles are used to illuminate the area. When the image is projected on the CCD, the circuits translate a digital signal to digital signal which are then sent via thin wires through the endoscope to a video monitor where they can be stored on tape and viewed on a TV screen. Fig 13a and b shows a videoscope and pictures taken by this device.
Conclusion:
During this study it has become obvious to me how important optics is in medicine. The advancement of medicine depends on these devices that enable physicians make better diagnoses and also precise treatment of different diseases. The endoscope eliminates guesswork and allows for viewing of internal organs and tissues in three dimensions which otherwise cannot be done without damaging tissue. This has been an overall learning experience.

References:
Books: Lasers and Optical fibers in medicine -Abraham katzir
Internet: www.medicalrecourses.com