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The Historical Evolution of Endoscopy

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Introduction

Many believe endoscopy to be a modern invention and instrumental concept developed within the last hundred years or so. It may, therefore, be surprising to some that the evolutionary steps that lead to what is now considered modern endoscopy are thousands of years in the making.

Endoscopy can be, and has been discussed in many different ways. Some reports choose to describe endoscopy as an all-encompassing section including instrumental innovations, inventors, technique, and the social history that played along side its development. This text will tilt the camera per say to provide a new insight on how the evolution of endoscopy should be explored. While the lives of endoscopy's pioneers are interesting, much of what is reported on this personal history is anecdotal. This text reflects on the structural development and evolution of the endoscope as a physical instrument throughout history. This perspective intends to provide the reader with an index of historical facts and milestone accomplishments of the endoscopic instrument with which they can further expand on a particular topic of interest and understand the great strides taken to develop this modern marvel.

What Is Endoscopy?

Considering endoscopy as an instrument can have many and variable definitions to the public at large. For example, Martin Culjat et al. described endoscopy as a "small telescope device(s) to look inside the body [that] applies generally to the optical devices (telescopes) used for endoscopic procedures"[1]. Obviously this is a very loose definition and one that is perhaps used in a non-technical setting. Kay Ball describes endoscopy as, "the inspection of body organs or cavities by means of an endoscope, which is a device consisting of a tube and optical system."[2]. This explanation hits a lot closer to what endoscopy means in regards to this piece. However, this text intends to be technical in describing the origin of modern endoscopes so a stronger definition is necessary.

One technique of accomplishing a definitive picture of endoscopy is to use a standard definition from an accepted authority, in this case the United States Food and Drug Administration, or FDA. This administration is the overseer of all medical technology, among other manufacturing processes. They define medical devices as, "an instrument, apparatus, implement, machine, contrivance implant, in vitro reagent, or other similar or related article, including a component part, or accessory, that is intended for use in the diagnosis of disease or other conditions or in the cure, mitigation, treatment, or prevention of disease, in man, or other animals"[3]. In contrast, this definition is perhaps too all encompassing while still being overly technical. Perhaps the best way to describe what is discussed in this text is to define endoscopy as a physical instrument, both as a whole device and the individual components that comprise it, which allow man to observe and manipulate the internal body.

In order to understand ailments of the body, "Early physicians sought a way to peer inside the human body, unlocking the secrets to understanding the form and function of organs and learning how disease originates and progresses, how injuries affect the body's system and structure and, most importantly, to offer surgical methods that promote rapid healing."[1] With the ability to access, visualize, and manipulate a patient's internals came the advent of new techniques and cures for disease and injury but more importantly the concept of minimal invasion to treat these internal complications.

Minimally Invasive Philosophy

Minimal invasion as it relates to endoscopy is like the body of an automobile without headlights or windows. It provided the vehicle to internal surgery even though it would take many years before proper and safe visibility allowed for directed driving. Despite the cons of poor accessibility and visibility for years (something easily noted since the technology has only really made true visibility possible in the last century or so) minimally invasive surgery comes attached with a long list of pros. This list includes chiefly, "offering less pain, shorter recovery times, and reducing scarring"[1] along with "patients usually experience less post operative discomfort and recover more quickly than patients who undergo more invasive procedures"[2] and "shorter recovery time, lower risk of infection, reduced postoperative pain and trauma to the patient, and reduction in hospital length of stay."[4] A smaller incision allows fewer bacteria to cross the skin barrier, decreasing infection, and smaller cuts mean less physical area the body needs to heal.

Although endoscopy today is most frequently viewed as a physical instrument capable of allowing minimally invasive procedures, its precursor is just that, the concept of minimally invasiveness, a "new philosophy" for many early physicians[5]. One of the earliest was Hippocrates II from 460-375BCE[2]. Hippocrates was a devoted advocate of reducing the amount of surgical action taken due to mortality risk, a concept that went against the grain of his time since traditional open surgery was considered the "gold standard"[5] (see figures 1 and 2 to compare open vs minimally invasive surgery). Hippocrates was on to something well beyond his time, an idea that the body should be left as undisturbed as possible so that it may heal itself as best as it can. This idea has been refined and developed through the years and applied to modern endoscopic technique allowing surgery to aid in a body's healing process by removing the diseased or injured portion while disturbing little else in the body.

Fig. 1 “Traditional open surgery”[4]

Fig. 2 “Minimally invasive technique”[4]

What Does It Entail?

Minimally invasive surgical procedures are more than just a concept or philosophy. As a technical text, definitions are obligatory. Culjat et al. define minimal invasion as “procedures … in which tools, instruments, or devices are inserted through small incisions to perform procedures with minimal patient trauma.”[3] This description is more than fair but could be broken down further for those readers unfamiliar with surgical protocol. In modern minimally invasive surgery one or more small incisions are cut in the abdomen and “A hollow, cylindrical device, called a trocar is inserted into each incision.”[4] An endoscopic camera is placed through one trocar allowing the surgeon to view the interior of the abdominal wall. The actual surgical instruments such as “graspers, scissors, or staplers,”[4] are placed in the remaining trocar channels acting both as the surgeon’s hands and methods of tissue dissection, and allows the surgeon to manipulate the instruments from the outside. The more advanced technology, becoming more available and common daily, uses image guiding in tandem with cameras and video monitors to provide the surgeon with the best possible visualization. Some imaging techniques are “ultrasound, fluoroscopy, CT, or MRI”[3]. However, while this text will touch on the use of image guided technology, since its advancement walks hand-in-hand with modern endoscopy, it will only be referenced in order to lightly include speculation on future device technology.

The Components

Once it is understood how minimally invasive procedures are performed, the components that comprise the instrument can be discussed in more detail. All endoscopes require two main functions, visibility and accessibility. Visibility can be broken down further to lens or optical technology, illumination, and camera technology. Accessibility can be accomplished by use of entering through an orifice or trocar, utilizing insufflation, and the type of tubing used. Some of “the most significant optical division arises in the difference between rigid and flexible endoscopic designs”[6] along with the distinct difference in natural and electronic illumination techniques. Other mechanical parts that commonly aid these basic functions include “a smooth sheath [and] stopcocks for introducing gases and fluids”[6]. While notable, these mechanical advancements are not considered as groundbreaking developments as those stated before it.

Much of what has been described already has been placed under the umbrella of endoscopy. However, this is not entirely truthful and should rather be described as “endosurgery [which] lead to many fields including arthroscopy, angioscopy, and laparoscopy”[4] along with “gastroscopes … bronchoscopes, and so on”[1]. The idea of “sub-specialization as we know it today did not truly exist”[7] in the early days of minimally invasive surgery. Each scope, as it was specialized for various parts of the body, would go on to be categorized as separate instruments in the 20th century but for thousands of years the practice was simply known as endoscopy. This text is thusly called the evolution of endoscopy due to the lack of specificity in definition for so many years and the fact that the basic scope used in minimally invasive procedures is so similar.

An Acknowledgement

Before delving deep into the historical origins of endoscopy it should be noted that the surgical pioneers acknowledged in this text are by no means an exhaustive list. Many surgeons have advanced the technologies and uses of endoscopy, later on to be separated into divisions like cystoscopy and laparoscopy, but did not perhaps invent or expand on the physical mechanics of the endoscopic instrument. For this reason they were not included. The main focus of this text is the physical advancement and evolution of the endoscope and the components that comprise it rather than the techniques and many procedural functions it is able to perform as it advanced. These techniques and procedures are looked at as examples to help the reader understand the importance behind the technological advancement. Furthermore, the pioneers presented in this text are acknowledged for their ingenuity in mechanics rather than their technical prowess.

Early History

Hippocrates may have been one of the first to strongly advocate a minimally invasive technique in regard to surgery, but he was not the inventor of such ideas. In fact, endoscopic-like tools and practices have been discovered in Egypt as far back as 1700-1600 BCE in a text called the *Edwin Smith Papyrus*[8]. This text describes endoscopic procedures and the rudimentary tools used for them but more impressively the text cites an older document from 2640 BCE[8] making it some of the earliest known writings about endoscopy. While it is well known that the Egyptians had always been interested in internal anatomy for religious purposes of death and burial, the book describes how to treat medical conditions of the living. It separates medical treatment into three categories, "treatable, treatable with difficulty; or an ailment not to be treated", the latter of which may be described by modern terminology as "inoperable"[8].

It was not until 1200 years later that this concept of minimal invasion using endoscopy was revisited and in another culture, Greek. Hippocrates, while not the inventor of the idea, was extremely influential in advocating minimal surgical intervention as a medical practice. Rather, he preferred to closely observe the patient to cure disease caused by lifestyle and the environment[8]. Although he more frequently prescribed "diet, rest, exercise and even music therapy" as means of healing, he also explored the realm of endoscope technology found in his book *The Art of Medicine* in 400BC[8]. His work describes in great detail how a speculum can be used to visually examine the rectum in section 5 titled *On Hemorrhoids* saying, "But if the condyloma be higher up, you must examine it with the speculum, and you should take care not to be deceived by the speculum; for when expanded, it renders the condyloma level with the surrounding parts, but when contracted, it shows the tumor right again."[8]

Just after the Egyptians and Greeks, the Romans also began utilizing endoscopic technique and instruments in the first century CE. Surgical tools have been unearthed in the volcanic ruins of Pompeii most spectacular of which are the specula and urinary catheters, which allowed a diseased body to be cured without an open procedure[3]. These three cultures began a chain reaction of peaked interest and discovery to uncover what lay beneath the abdominal wall. However, it would take quite some time before the obstacles of visibility and accessibility of the interior body could be overcome enough to allow practical guided surgery.

Visibility

Although being able to see the inside of the abdominal cavity can not be accomplished without actually accessing and entering it, this section was placed first because early endoscopes were inserted through incisions unaided by trocars or insufflation. Visibility, which includes lenses and optics, illumination, and camera technology, also had some of the most difficult hurtles to overcome in comparison to the most basic method of accessing the interior of the body by an incision. Visualization is also the most changed from its humble beginnings to modern technology in contrast to the relatively same accessing techniques throughout time.

It often feels as though history has woven a tapestry of events. It is difficult to pin down a distinct timeline of mentionable invention dates because each piece of the inventive puzzle was worked on and improved over a long time span of years. When placed in chronological order the advancements in technology seem to bounce from lenses to cameras to lighting and back. Thus, while many technologies advanced at the same time such as microscope lenses, refractive mirrors, and illumination techniques, often by the same inventors, it seems easiest to discuss them as separate inventions. For this reason they are placed in their own respective section since they carry equal importance to the overall invention that is the modern endoscope. Many of these technological pioneers will be acknowledged for their multiple inventions by referencing their inventions to other sections of this text.

Lenses and optics:

Early Development

Lenses are a relatively modern invention. Optical lenses had been in existence since the early 11th century, but none were ever advanced enough to actually justify using them to magnify more than a line or two of text for ease of reading. It was not until 1683 when a Dutch scientist, Antony van Leeuwenhoek, invented the microscope lens[9]. His desire to view bacteria in a Petri dish was the first step in true visualization and magnification of small, localized areas[9]. Leeuwenhoek got the ball rolling and 27 years later the next advancement in optics evolved.

By 1710 there was a leap in optical technology, which was nicely summed up in a textbook called *The First Optical Instruments as Allegorical Depiction* by the German author, Johann Michael Conradi[10]. His text was written as an historical evolution of optics up until that point. It included advancements on prisms, “magnifying glasses, microscopes, lenses, a lamp case, and a conical mirror (both flat and curved) used for distorting”[10] and image. Beyond these optical components, he included diagrams of optical instruments that later inventors, such as Bozzini, Nitze, and Trouve, would use and expand upon[10].

Early 1800s

In 1805 the Italian-German physician, Philip Bozzini, took his predecessor’s ideas of optical technology and expanded them to create a light transmitting device called “the lichleiter” and thus “modern endoscopy was born”[6]. He was the first noteworthy inventor to attempt visualizing the interior body and therefore many consider him “the father of endoscopy”[11]. Part of his invention, the use of candles and mirrors to reflect light to the appropriate area, was not a new idea[6]. In fact, using mirrors to reflect light had been used since 912 CE[6]. He also used the same lens system described by Conradi in 1710[10]. Bozzini's contribution was combining the previous technology into one instrument and developing a lens that reflected the internal images back to the eye[11]. The lens was comprised of two aluminum tubes with strategically angled mirrors inside, a combination of flat, concave, and convex, that were placed in such a manner that the image was transmitted to the eye while the 'image' of candlelight was reflected to the distal tip of the instrument and into the interior body[11]. Bozzini described his instrument with pride by stating, "Surgery will gain not only from the new operations that could not easily be performed until now, but also all other uncertain operations, which depended on mere luck and chance, will now be relieved of uncertainty by the influence of sight."[11]

Small advancements were steadily being made over time. One such example was the "speculum autostatique" which included a more complex lens system comprised of dual microscopes developed in 1834 by French physician, Jean Pierre Bonnafont[12]. Although the technology of instrumentation and procedural techniques had been advancing in Europe, America seemed to have been held back by the societal pressure of what was considered both decent and the most effective method of treatment. However, despite the societal pressure, Boston physician John Fisher employed a new type of lens system based on a periscope, in 1824 (more impressively while he was still in medical school) [12]. This style of lenses allowed him to view the more troublesome angles in the body[12].

There is a controversy in regard to the title 'father of endoscopy'. Clarice Powers believes that the title should not go to Bozzini, but rather belong to a French physician named Antonin Jean Desormeaux who was considered to have "invented the first effective endoscope in 1843"[13]. This is partly due to his invention of the word "l'endoscopie" to describe his new instrument[14]. Two of the aspects of visualization made this device a success, better illumination (discussed in the next section) and new lens angles[14]. By changing the placement of the lenses so that light was reflected sideways Desormeaux was able to concentrate his light source more precisely in one specific area rather than the unfocused light of his predecessors[14]. With better visualization Desormeaux claimed to have visually diagnosed and treated bladder stones in contrast to previous procedures that were "performed semi or entirely blind"[14].

Mid 1800s

Although all of these fantastic developments were being introduced, up until the late 19th century the lenses still defined visibility[15]. That is to say, the field of vision within the internal body was still only as large as the physical size of the lens. The observable field was no larger than what the diameter of the scope allowed. It would take a great leap in understanding optical lenses to break through this barrier.

Surgeons were progressively improving on lens technology for their own practical use in instruments as needed. One notable inventor was a urologist from Dublin, Francis Cruise[16]. In 1865 he was able to considerably improve the lens structure of endoscopes when he combined a binocular system with the structure[16]. Two ocular pieces create a stereo view for the eyes and improves visibility. He also greatly improved on Desormeaux's illumination source found in the section below. Parisian engineer Trouve was similarly well known for his advancements in illumination, but more noteworthy for this section were his improvements in optics. In 1873 Trouve created a dual prism arrangement in the scope which, when artfully placed, increased the previous field of vision from a static view to 90 degrees[15]. He also made the eyepiece a built-in module that included a magnifying glass able to zoom 2.5x[15].

Two other pioneers, Czechlasovakian Johann von Mikulicz and Joseph Leiter from Vienna, also paved the way to illumination[7]. But, like many inventors, they developed endoscopy in more than one way. In 1881 the two men improved the current optical system in circulation by incorporating a prism[7]. It should also be noted that they were one of the first to advance tubing technology to be discussed in its respective category. Although Trouve had already introduced prisms into his circle of peers, Mikulicz and Leiter were the first to do so in regard to their own procedures and in combination with their respective illumination and tubing designs.

Maximilian Carl-Friedrich Nitze was the next innovator of design. In 1877, the German urologist applied the cutting-edge microscope technology of the time to the endoscope and expanded its field of vision[15]. The set up of lenses he used was a combination of three separate lenses, Dr. Cameran Nezhat et al. describes them as, "essentially a mini microscope that included a wide angle lens which was fully immersible in the watery environment of the bladder. The second lens produced the combined objective, and the objective reflected the image onto the middle lens with as little light loss as possible at that time, which then magnified the image even more."[15] Improving magnification and widening the field of vision were major advancements in being able to visualize the interior body. He also visualized improvements on the light bulb, an advancement discussed later. However, even though these optics were vast improvements, the image directed back to the eye was still upside down!

Early 1900s

Nitze continued to improve his designs over the years and in 1903[17] expanded the field of vision once more. He designed a "retrograde view" scope that had the ability to look at the bladder from all directions[17]. He accomplished this feat by turning Trouve's prism system into a small 3-in-1 telescope for endoscopy[17]. Most inventors exchanged ideas back and forth, improving on each other's designs. With Nitze's ideas out in the open, Ringleb was able to improve on them. In 1908, Ringleb solved what has been called "Nitze's error" of the upside down image[17]. He added another set of optical lenses that reversed the image[17]. Ringleb also increased overall magnification and the viewing angle of the lens, which made the total resolution higher[17]. However, although the viewing angle was greater, Ringleb actually decreased the field of view so that his improvements on illumination, considered below, would not decrease brightness as much[17]. This thoughtful design was so all encompassing in regard to total visualization, that is optics and illumination, that Ringleb's scope was still being used until the 1960s[17].

Although it is an amazing accomplishment to have a persistent marketable design, like Ringleb's scope, lens technology in endoscopy did not change after that until nearly 70 years later and what did change were only minor alterations on Nitze's basic design[18]. Ringleb made Nitze's design sustainable through the years when he inverted the image and increased the field of vision to 44.2mm in diameter with a now relatively small range of 2.5cm[18]. Late into the 19th century, the viewing angles were still only between 80-85 degrees[19]. Furthermore, magnification issues put more complex surgical operations on hold and it was slow to advance, gaining only 20x magnification by 1930s compared to modern technology that provides 80x magnification[18].

Again, optics evolved but in small steps. One innovator to inch forward was the Danish surgeon Severin Nordentoeft who, in 1912, rather than using glass as a lens used a saline solution as the optical channel through which to view procedures[20]. Using a liquid solution supposedly allowed him to see the inside of the knee with superb detail[20]. Another inventor, Joseph McCarthy from New York, also made advancements in visualizations. In 1923 he extended the field of vision by creating a "foroblique lens system"[17].

Heinz Kalk, a German gastroenterologist, was a milestone inventor and it has been suggested that he was more than the founder of the German school of laparoscopy, but also the "Father of Modern Laparoscopy"[19]. Part of his innovation and the inspiration that drove him to invent was his concern for the great amount of fatality rates that were common with early endoscopic procedures. High fatality was often a cause of blind operations[19]. He therefore desired superior visibility with which more effective biopsies could be performed with greater precision. In 1929[13], he presented his own modified version of McCarthy's foroblique lens[19], which allowed a 132-degree diagonal viewing angle[13].

Across the Atlantic an intern in Los Angeles named John Ruddock modified his own version of the endoscopic optic system. In 1934, he introduced a revised version of McCarthy's scope he called the "foreblique visual system" that had the ability to visualize a larger area of the abdominal interior[19]. His system utilized an indirect 45-degree angle in contrast to the previously used 90-degree angle, a subtle change that resulted in far superior visibility[19]. His optic structure is described as "one of the most sophisticated and crucial innovations" that was unified into one "smooth operating unit"[19]. Later in his career, Ruddock became one of the first to use photography with scopes, an aspect of his inventiveness discussed camera section.

Mid 1900s

By the 1950s visual advancements in illumination and camera technology were picking up speed. Lens systems were also keeping pace with the times when in 1957 Raoul Palmer, a French gynecologist, developed the most powerful magnification found in lenses to date and more impressively in the smallest tube package on the market, a 5mm scope[21]. However, it was the 1960s technology boom that really developed optics for endoscopes, as we know them today.

How Lenses Work

At this point lenses have evolved from the humble single glass optic to a multi-layered prism including system of optical advancement. With the background of the step-by-step changes each inventor made to optics through history it is prudent to explain the technical mechanics that now build the layers of the endoscope. The "conventional" endoscope is usually made up of "a prism, and objective lens, a "train" of field and relay lenses, and an eyepiece"[6]. Those endoscopes in which the image is viewed straight on with a receiving angle between 170-180 degrees are called "direct vision"[6]. Direct vision endoscopes can also have an angle of 90 degrees if a prism is involved[6]. If the lens is placed at an angle that is less than half the field of view, the device can be rotated 360 degrees about a central axis to increase the line of sight[6]. For example, if the visual range is 90 degrees and the lens is tilted at a 45 degree angle or less on the distal tip of the endoscope, the scope may be spun around in its sheath 360 degrees to create a view of the cavity like a dome. The glass called the "objective lens" is that which determines the line of sight[6].

A majority of lenses found in the scope tube determine the intensity of magnification, but the objective lens is unique in that it is the only lens that has control over visual range[6]. The objective lens is also contoured like no other lens because the external surface is curved while the internal surface of the glass is flat[6]. Due to this specific design, the objective lens also has control over how much the image may distort at the edge of vision, usually a level of compression[6]. Finally, this lens is also responsible for inverting what had previously been an upside-down image[6], as mentioned earlier, a complication solved by Ringleb.

A light source is obviously necessary to view the dark interior of the body, but lenses transmit that light in a focused manner through the scope then usually into the abdomen. The lens that redirects the light source to the interior of the scope is called the "field lens". The light is then transmitted down the long, narrow shaft of the scope through a series of many "relay lens[es]"[6]. The brightness of the light and subsequently the reflected image depends on these relay lenses[6]. Furthermore, the relays should prevent "vignetting" or a shadow around the edges of the image[6]. Of course, accuracy in cutting each lens and precise placement of these pieces is absolutely crucial for optimal function.

In order for the viewer to actually see the image reflected by all these lenses, a lens called the "ocular lens" is attached at the proximal tip[6]. This ocular piece is actually made up of a few less expensive glass lenses[6]. This series of lenses transmits the illuminated image along with magnifying it to the ocular piece for the user to see[6]. It is onto this ocular lens that the first photography units used by Ruddock were attached, along with modern camera lenses[6]. The camera took its position as the eye so that video monitors could be used while the surgeon was standing rather than him bending over to look into the scope.

The Modern Age of Rods

A British physicist named Harold Hopkins could arguably be considered the most prominent inventor and pioneer for endoscopic visualization. In 1967 he devised an optic system that used "large quartz, rod-shaped lenses" that not only significantly enhanced the image projected to the eye, but also is a device still used in modern day scopes[13]. The transmission capabilities of the quartz drastically improved illumination as well, an aspect discussed in the next section. These quartz rod-lenses also helped the endoscope be engineered to a smaller diameter because of its extraordinary illumination and exact illustration of image[1].

How Rods Work

Once it is understood, the impact of Hopkins' inventions for modern endoscopy and how it actually functions can be explored. Most quartz rod-lenses used for endoscopy are comprised of two main halves: the "proximal end" or the end of the instrument closest to the physician that has an "optical coupler" through which the user can visualize the internal body[1] (often more modern scopes have a video camera attached to this portion and use a monitor for visualization), and the "distal end" or the tip inside the patient that contains the magnification lens[1] (or for video endoscopes, the camera lens). The instrument also has a light attached to the lenses to illuminate the interior body, a tube on the outside that holds the illumination and lens-rods together, and an open channel that can have instruments attached for manipulation[1].

The advantage of Hopkins' rod-lens system boils down to the fact that the rod-lenses were much longer than they were wide[6], compared to the classical lens series that used many lenses of short length and wide diameter. Classical systems had a large number of "air-glass interfaces" which prevented them from obtaining the superior image quality including "brightness and clarity" that the rod-lens could[6]. Again, the advantage of the rod-lens, being its greater length and smaller diameter, allowed it to be manufactured easier since it had a "decreased tendency for the lens to tilt"[6]. However the high glass content of the endoscope's interior made the devices more prone to cracking if they flexed[6]. While this was not a major issue for rigid endoscopes, flexible scopes would need Hopkins' later invention of fiber optics to function without breaking.

The Modern Age of Fiber Optics

By the 1970s Hopkins' quartz rod-lens had evolved into a "flexible fiber optic" made from thousands of glass fibers[13]. Small one- or two-man inventors were now being supported in collaboration with expert teams from companies such as "Storz, Olympus, ACMI, and Philips"[22]. Modern endoscopy developed basically overnight toward the technology currently being used. It is easy to understand this immediate jump toward modernity due to "clear and color-true images, with a breathtaking 3-D like field of vision with a depth of field never before imagined"[22].

How Fiber Optics Work

Hopkins' fiber-optics were developed by "heating a segment of glass rod until it is molten and then stretching it rapidly [to] create a thread-like fiber with altered physical properties"[6]. These threads ended up being far smaller than a human hair, ending up with a diameter between 5-25μm and having the ability to flex without breaking[6]. These long glass fibers also preserved their capability of conducting light through "internal refraction" and in an ideal world none of this light was lost beyond that which was internally absorbed by the glass itself, a system known as "optical insulation"[6]. Easy manufacturing combined with the fibers small size and flexible properties while still being able to sufficiently transmit light made fiber-optics the first choice over traditional short glass lenses and later Hopkins' initial rod-lens design.

Light cannot be transmitted by individual fibers since they are too weak on their own. Therefore, thousands of small fibers are combined to intensify the light being transmitted[6]. This bundle of fibers combines the two most basic necessities of visualization: illumination of the interior body and transmission of the lighted image to the user's eye or camera[6]. To clarify, there is one bundled unit of fibers that have been separately insulated into those two units for lighting and reflecting the image. The illumination bundle is just that, a non-specific arrangement of fibers called an "incoherent" blend[6]. However, the fibers in the image bundle must be organized in such a way that the pattern found at the distal tip is the same at the proximal end[6]. Each fiber transmits one piece of information like one pixel on a computer screen. Those 'pixel' images must line up in the exact manner they accepted the image inside the patient so that the image the viewer sees is the same coherent image. This arrangement of the image bundle is called "coherent"[6].

Modern endoscopes that use Hopkins' fiber-optic technology can be made of flexible tubing rather than the rigid scopes of past designs. Fiber optics replaced the "standard relay assembly"[6]. The resolution of the image reflected back to the user is higher than were classical endoscopes[6]. It should not be forgotten that this resolution still depends on the physical structure of the fibers. When the fibers are regularly spaced, with an even density, they transmit the highest quality image[6]. More fibers translate to more 'pixels' in the analogy above, but when the fibers are much smaller than 5μm their physical strength and structural integrity are lost and fracturing becomes a concern[6]. It is for this reason the range of 5-25μm has become standard. Another advantage of many small fibers are their ability to allow the reflected image to be transmitted with high precision and clarity even when the bundle is curved.

Illumination:

Ancient Development

Many of the inventors described in this section have also made advancements toward optical lenses and thus have been discussed in the previous section. To gain a full appreciation of how innovative each of these pioneers were one should begin by reading the lenses and optics category.

In tandem with the development of optical lenses was the ability to harness light in order to illuminate the dark interior that is the body. Egyptian medical records found in the *Papyrus Ebers* dating back to 1550 BCE describe using a full and direct sun to examine the nasal cavity[23]. Middle Eastern culture advanced the next step in illumination by combining candles, oil lamps, and sunlight to produce a more brilliant source and mirrors with which to focus them[8]. An important figure from this culture is Abulkasim (or Abul Qasim) from 912-1013 CE who was the first in written history to utilize reflected light from a mirror to view the cervix[6].

Early Development

Physician Arnold de Villanova reintroduced candlelight to the medical world in 13th century southern Europe as a means of illumination[23]. However, “artificial light” was not introduced until 1500[9]. An Italian researcher called Gerolamo Cardano, known for his mathematical skills and medical work, developed a mechanical lantern to view the dark interior of the body[9]. Only decades later, in the same country, a man called Giulio Cesare Arranzi (or Aranzio) used the basic principles of “camera obscura” to reflect, direct, and focus light[9]. To examine his patient’s nasal cavity he directed candlelight through a glass flask that was filled with water, which allowed the light to be more focused on a central point[23]. It should be noted that other sources claim he used sunlight that had filtered through window shutters of a dark room as his illumination source[9].

A century later in France, Pierre Borel, King Louis XIV personal physician, used the current knowledge of mirrors to invent a concave mirror[9]. The concave dome shape allowed light to be reflected more accurately and brilliantly[9]. One hundred years after the design of this concave mirror, in 1729, an army surgeon[23] from Britain named Archibald Cleland developed a “biconvex lens”[10]. Documentation shows that he used this biconvex lens like Borel’s mirror to redirect and magnify the light of a candle in order to look into the nose[10]. Although not the most popular method, Cleland was said to have stated that “he appreciates [what was] still constructed by himself”[23]. It was pioneers like Cleland who, by sticking by their inventions, pushed the field of endoscopy.

Early 1800s

The next major milestone in the history of illumination was in 1805 with Philip Bozzini[13]. The reader is already well aware of his accomplishments regarding optics, but there is a reason his device was named the "Lichtleiter" or "light transmitter"[24]. The Lichtleiter harnessed the candle and mirror light source similar to his predecessors, but also included light transmitting lenses and a reflective tube that allowed his focused light to reach the distal end[24]. His curiosity inspired him and he is quoted as saying "I had the idea of illuminating the interior cavities of the living body" since "visualization is better than finger palpation"[24]. He predicted quite rightly that given certain improvements, an illumination device such as this could be applied in many different medical realms of the body[24]. His suggestion became the precursor to subcategorizing the scopes based on their respective surgical procedure.

There is a short lull in optical innovation for about 20 years until French urologist Pierre Salomon Segalas introduced a "new and improved" endoscope called the "speculum urethra-cystique"[12]. His invention was considered an improvement on Bozzini's instrument because it was easier to use according to a few in the field at the time and Segalas himself[12]. The primary design changes, compared to Bozzini's scope, was his inclusion of a larger conical mirror that was able to grab more useful light and refocus it to the area being examined[12]. His illumination source was also brighter because he used the combined light of two candles rather than Bozzini's one[12]. Furthermore, Segalas painted the ocular tubes black in an attempt to decrease the amount of light scattering[12]. While each of these inventions were spectacular on their own, it is their combination that was really impressive. It should not go without saying that there were some setbacks. Although Segalas had the advantage of more vibrant light with two candles, the two uncovered candles introduced a real fire hazard to the operating theatre[12]. The uncovered candles were the design feature that helped Segalas's device gain popularity for being easier to use compared to Lichleiter's heavy and large metal lampshades[12].

The years move on to 1824 when it is appropriate to look back across the Atlantic toward the medical student, John Fisher of Boston. His periscope-based lens designs were important in the evolution of endoscopy, but it was his drive to create an "instrument for the illumination of dark cavities" that lead him to make great strides in lighting[12]. Initially Fisher built a mechanical lever system of wires that raised and lowered the candle light source for ease of mobility in guiding the "focal point of the light"[12]. His next suggestion for better illumination was to use a heated galvanized wire, an idea we now know as the forerunner of Edison's light bulb[12]. Despite his ingenuity, Fisher, like Bozzini, saw room for improvement and stated that his own designs were "easily susceptible of improvement"[12].

Not everyone was as creative as Fisher. Electricity would not be incorporated into endoscopy until much later and inexpensive, easily attainable light sources like candles were still the most effective during this time period. What is more, milestone advancements in illumination were slow moving without electricity. In 1834, Jean Pierre Bonnafont, initially known for his double or "two-leaved" microscope lens set up, devised, and utilized a "conical mirror" like Segalas, which noticeably increased the amount of focused light[12].

Mid 1800s

After years of using candles as the primary light source, Antonin Jean Desormeaux, the Frenchman who invented the word "l'endoscopie", began exploring alternatives[14]. In 1853 he determined that a liquid mixture of "four parts 96% alcohol with one part turpentine" to be added to a flame and called it a "gasogene" lamp[14]. The light produced from this unique gas lamp was significantly brighter compared to candlelight[14]. Brighter lights equals brighter focused light and consequently better visibility for biopsies[14]. However, like Segalas's threatening fire hazard, Desormeaux faced the consequence of a thick "sooty, smoky residue" from his gasogene lamp[14]. During pelvic examinations the high heat of the flame was also problematic since it tended to either burn the physician's face or the patient's thighs[14].

Francis Cruise, the Irish physician that featured binoculars in his scope design, saw Desormeaux's gasogene lamp and decided to improve upon it[16]. In 1865 he combined petroleum and camphor as a fuel for his lamp[16]. The resulting light was brighter and it conveyed true color better than Desormeaux's version[16]. The flame from Desormeaux's lamp was more rounded which produced bright but not wide spreading light where as Cruise's lamp had the advantage of a "flatter flame" that could reach further with greater brilliance[16]. The fuel mixture Cruise concocted did not leave soot like Desormeaux's flame, but it did have the same burn potential for patient and practitioner[16].

The quality and type of light are important, but factors such as proper focus and reflection are equally as important. With this knowledge Cruise included two additional attachments to his scope. The first was a reflecting apparatus that reflected the gas-flame light off of a "collimating lens" and was attached to a clamp that could be raised or lowered as desired[16]. The second attachment was the now familiar concave lens, used to focus the reflected light into the patient's body[16]. Small tinkering adjustments like Cruise's modifications helped illumination evolve stepwise toward the twentieth century.

Gaining experience and understanding of the past in order to transform the future is a necessary aspect in technological evolution. Alexander Wilhelm Ferdinand Ebermann did just that. He heard of Desormeaux's illumination attempts and decided to learn from him, traveling all the way from St. Petersburg to Paris to do so[16]. In 1865, combining the knowledge from Desormeaux with an illumination product called the "jablonchkow light" Ebermann created a lantern that would be worn on the head or clipped to the scope[16]. The lamp's design has been "described as an 'electrical ball of light' with a center composed of carbon tips"[16]. Allowing the light source to be attached to either the head or endoscope freed the hands, making procedures easier overall. Yet, the device was still awkward to handle because the batteries were bulky although necessary as an electrical power source for the wires[16].

Nearly all of the illumination attempts up to this point used some form of light source that was reflected and focused on the inside of the body. Julius Bruck, a German dentist, challenged that model by thinking out of the box, or rather inside the scope[16]. In 1866, Bruck built a preliminary light bulb out of galvanized wire enclosed in a glass tube and cooled with flowing water[16]. The wires were encapsulated in one compartment while a second compartment surrounding the first had attached tubes to allow inflow and outflow of cool water[16]. The bulb was then placed on the distal end of the scope and therefore inside the patient[16]. Bruck named this contraption a "galvanoscope"[16]. This was the very first time that the body was illuminated from the interior, a design that fundamentally changed visibility.

One inventor in particular, Maximilian Carl-Friedrich Nitze, was a game changer in illumination for endoscopes. He advanced many different aspects of the scope beyond light, one of which can be read about above in optics. His advancement in this particular procedural realm of the bladder gives him the title "father of modern urology" by Nezhat et al.[15]. Driven by complications in visibility for his biopsies, Nitze accomplished what Bruck could not, designing a light source that was practical to use in the real world setting of the surgical room[15]. His first attempt was remarkabley similar to Brucks's design, which was a bulky platinum wire that tended to over heat and had to be cooled with circulating water[13]. However, his designs took a sharp turn when Edison introduced the first light bulb in 1880.

Just prior to Edison's bulb, in 1873 the French inventor Trouve, already recognized for his "double prism system" above, took Nitze's design one step further[15]. He too used a heated platinum wire design for his light source but in contrast to Bruck and Nitze, his wire did not overheat and therefore did not necessitate bulky tubes and water to cool down[15]. Trouve designed his wires to not to overheat by hammering them flat between "1/14th to 1/6th mm thick"[15]. These wires were dubbed "thin platinum filaments" to distinguish them from their wire predecessors[15]. The filament's greatest advantage was their ability to still conduct current while drastically reducing the heat output[15]. With the same level of illumination and less heat, the product was safer without compromising visibility making "every examination…possible" as Trouve suggested[15].

The late 1800s abounded with many pioneers in the illumination division who all made advancements one right after another. This creates quite a complex web of dates to look at since many different inventors introduced many designs all within each other's lifetimes. With that said, the time line jumps to 1874 with the German inventor, Theodor Sigmund Stein[15]. Although he is more well known for his advancements in camera technology, a subject discussed in the next section, he did improve illumination. When the medical world was using platinum, Stein was using what he called a "gas magnesium light"[15]. This involved a heated magnesium wire that gave off a much brighter and whiter light than platinum[15].

Platinum was still the most common light source for this era. A Czechlasovakian named Johann von Mikulicz, in partnership with Joseph Leiter of Vienna, were among those who used platinum to illuminate the tip of their scope[7]. Together the two men absorbed current technology, specifically Bruck's work, and created their own design involving a galvanized platinum wire formed in a u-shape that was then placed inside a "double-barreled glass tube surrounded by tiny hollow circuits"[7]. The exterior enclosure contained water that could be circulated using the circuits as canals[7]. All of this was placed on the distal end of the scope and an "external Bunsen battery unit" was found on the other end to power the wires, allowing them to glow[7]. Mikulicz and Leiter's design changes may seem insignificant but it is the small steps, such as improved water circulation to keep the light cooler for safety reasons, which really evolved endoscopic illumination. Furthermore, this was not the only development the two pioneers made. They were also known for a prism optical system and a "modular" tubing set up, an accessibility improvement that should not be overlooked[7].

Edison's light bulb was the next most revolutionary step in illumination for endoscopes, and therefore visibility of the interior body. Scottish inventor, David Newman, was the first to recognize Edison's light bulb as a potential source of illumination for endoscopes. In 1883 he connected one of these bulbs, called a "mignon lamp" or small filament light bulb, to the distal tip of a scope[15]. This was perhaps one of the first illumination sources that truly did not need cooling and therefore could be used, as is[15].

While all of these steps were being made after Nitze's original platinum wire design, he continued working throughout his lifetime to improve the design himself. By 1888, Nitze had also taken Edison's invention and miniaturized it[15] in order to fit on the distal tip of his scope[13]. This design was called a "practical operating cystoscope"[15]. The advantages of having a better light bulb, one that is perhaps more familiar in design to modern bulbs in contrast to Bruck's platinum and water cooled conglomerate, was its ability to be produced on a larger scale due to cheaper materials, its simplified design that made it easier to handle, and the far lower risk of overheating and burning both patient and physician making it safer to all[15].

Although Nitze and Newman's miniature light bulbs did not require a cooling system to prevent burns, they still produced low levels of heat. There were some attempts made toward the invention of a cold light but little is known about these inventors. Nezhat et al. describes an invention of a "cold mignon bulb" made by a man named Valentine in 1895[15]. That same year the inventor Preston was said to have adapted Valentine's design to his own which became known as the "Preston cold lamp"[15].

Both of these cold lamps intended to trade the hot electrified wire with a "pea sized" light bulb[15].

Early 1900s

Near the beginning of the 20th century, endoscopy had its own sure place in the medical field and is one of the "preferred diagnostic method[s] over open procedures"[18]. It had taken thousands of years to evolve from the humble natural source of the sun, to candles, then electrified wires, and finally the light bulb as a suitable light source. By this time in history "organs could now be visualized in living color, just as they existed within the living body"[18]. Though the light bulb may seem such a simple invention, compared to modern times it is what presented the solution to illuminating the minimally opened, and thus dark interior of the body[18]. The light bulb provided a "bright yet soot-less, streaming beam of cold and consistent light, which could be safely placed inside the body"[18]. Rather than worry whether or not their patients or they would be burned by wires or flames, medical practitioners could concentrate on their technique instead[18]. By 1900, this piece of mind would become widely accessible in the form of miniature attachable light bulbs[18].

Unfortunately, the electricity used to power light bulbs was another complication. In the early 20th century, electricity was not sufficiently understood to safely be applied to surgery[18]. As a result, batteries reacted unpredictably and caused numerous serious accidents like "thermal tissue damage, electrocution, and other serious mishaps"[18]. Understanding electrical currents in order to utilize the ideal level for these instruments was an important task for engineers in the 20th century and a complex problem that would not be fully resolved until the next century[18].

The light bulb became the standard illumination for over one hundred years. One major pioneer who contributed to a better light bulb was Otto Ringleb. His name may be familiar for his inventions in the optics field since it was he who used lenses to right the previously seen upside down image endoscopes showed. Like many in the medical field he also looked at Edison's light bulb and sought higher quality illumination. In 1908, Ringleb made his own bulb using various filament metals like tungsten and osmium, which did not give off substantial heat and were safe to use inside the body[17]. These bulbs were considered higher quality and were used to produce endoscopes later on[17]. Ringleb also changed the shape of the bulbs to increase what is known as the "light field" or area of light that has a high enough usable brilliance[17].

It would take another forty years before anyone truly thought beyond this point. However, in 1941 Jason Brubaker and Paul Holinger began experimenting with cameras[21], a field that will be discussed in the upcoming section. In order for their film to have sufficient light to capture an image, they used a "proximally placed magnesium flash bulb"[21]. This was the first time a light source had been suggested to be used outside the body since candles[21]. While it may seem that Brubaker and

Holinger were taking a step back, in reality they were working backwards. They started with the most brilliant light source of their day and worked to modify it to the needs of endoscopy. Alas, their suggestion was not often used because of its excessive bulk and high heat that emanated from the bulb[21].

Mid 1900s

The familiar face of Raoul Palmer, already commended for his powerful lens system in a smaller endoscope package, made a major step in progress toward modern endoscopic lighting. In 1952 he developed a precursor to Hopkins' fiber optics when he presented "quartz rod lighting" to the medical community[21]. Palmer acknowledged his own invention as one that would go down in history in his comment, "Laparoscopy became a practical method only when the illumination became 100 times more potent" noting his own technology as the next step in that process[21]. Quartz rods, which are explained for their optical properties in more detail in the previous section, would go on to help Palmer develop color film movies of biopsies[21].

In the 1950s the use of film in combination with endoscopic procedures was becoming more common and was a major inspiration in developing better lighting. One physician influenced by film was Albert Decker at the Gouverneur Hospital in New York[21]. Decker made significant steps in endoscopic cinematography, an aspect of his career described in a later section. Unfortunately, he ended up vacating this portion of development because the extra lighting needed to produce a decent image proved too risky since it damaged the patient's body with its high heat output[21]. Bright light was important for cameras to function properly and provide the best image output possible. The down side was that the best light sources possible in the 1950s still produced far too much heat to be used safely.

Palmer's quartz rods, however, were not forgotten. In fact, German surgeon Han Frangenheim was one of the first to use Palmer's rods in practice[25]. Curiosity and the desire to continually improve drove him and other pioneers to push the boundaries when the rest of the medical community remained stagnant. Frangenheim provided many improvements to minimally invasive surgery along the way in various fields including film and insufflation[25]. He was also one of the first proud members to begin using fiber optics when they were first introduced[25].

The Modern Age of Fiber Optics

In 1960 another German, Dr. Karl Storz, took advantage of his predecessor's designs, specifically Palmer's quartz rods and Hopkins' rod lens, to produce what can be called the official "first" of "cold light technology"[26]. The 1950s boom in camera technology had influenced Storz but he saw its progress hindered by lack of proper illumination[26]. Light sources during this era had major drawbacks. If the illumination was sufficiently bright, it could cause burn hazards or on the other hand efforts to increase safety by lowering the heat output noted that the radiance of the light was significantly compromised. Storz realized that the solution would have to produce both great brilliance and generate low heat[26]. When Hopkins invented fiber optics, originally designed to broadcast images only, Storz saw them for their potential to transmit light as well[26]. Storz combined the transmission ability of Hopkins' fiber optics with the amplification of Palmer's quartz rods to produce a light source "specially designed [for] extracorporeal flash systems" or illumination outside the body cavity[26]. This unified system produced the most detailed and clean image yet in history[26]. Better image quality and no threat of burns created a safer minimally invasive practice that could be used not only for diagnosis but long surgical procedures as well[26].

Fiber optics quickly became the light source of choice then and is still used today. The risks of burns attributed to the variations of Edison's incandescent light bulb were abolished for good when Storz introduced cold light in 1960[13]. Fiber optics are comprised of cables that have a "core of glass known as cladding"[13]. A light source, sometimes incandescent bulbs or more recently LEDs (light emitting diodes), is attached to the cable on the proximal end to ensure that any heat produced from this "hot" source does not harm the patient[13]. The light is then reflected sideways continuously down the rod shaft until it transmits through the distal tip as cold light[13]. So, while the actual source of light may be obtained through traditional hot bulbs, the light that illuminates the interior of the patient remains cold. This set up of reflecting light from the outside has been understood since ancient times, but it was necessary to move through trial and error, which drove the evolution of illumination to this point.

While the lens has remained relatively similar since its beginning, illumination has evolved from a large assortment of light sources beginning with the sun, then candles, oil, and gas lamps, all of which required reflection into the body. Moving to "miniaturized incandescent bulbs attached to the distal tip of the endoscope"[6] that brought the light physically inside the patient. Finally leading to fiber optics that unified a hot light source from outside the body to a cold reflected source inside the body[6].

The modern endoscope still faces challenges since it needs to produce the brightest view of our dark interiors as possible to obtain a clear image. There are various aspects of light that need to be studied such as "light intensity, depth and focus, magnification, contrast, and resolution"[1]. All of these factors help produce an accurate representation of the body's interior so that a surgeon can differentiate between healthy and compromised tissues that may need his attention[1]. With the advent of HD camera technology, illumination is challenged once more due to the camera's "lower sensitivity because of the smaller pixel size"[1]. For this reason, light sources attached to HD setups are often a "300W Xenon light", an intensely powerful white light[1].

An illumination source called "low-loss optical fiber"[27], a product of the Corning company, can be used to help the reader gain deeper understanding of how illumination works for endoscopes currently on the market. This product is described as a "flexible filament of high-purity glass capable of carrying information encoded within pulses of light over long distances with low attenuation (signal loss)"[27]. This product is still on the market but was first invented in 1970 by "Corning scientists Dr. Robert Maurer, Dr. Peter Schultz, and Dr. Donald Keck"[27]. It works by transmitting video camera information and light through the glass fibers "by a process of internal reflection"[27]. The light is provided by an external source to the distal end and the video information is interpreted by computer chips in a cable box connected to the proximal end[27]. Although the concept of this product is relatively the same as its debut in 1970, it has advanced significantly since then. Initially, "low-loss optical fiber" had a "total attenuation (or loss) of 17dB/km" in other words the loss of optical light power measured on a logarithmic scale[27]. In 2014 the total optical loss, or attenuation was 0.17dB/km, which is a decrease in loss of 100 times compared to what was available 1970[27]. This improvement in illumination is true of nearly all-modern endoscopes, not just Corning. The medical field will continue to advance where lighting is concerned in an endeavor to produce a more true-to-life image.

Cameras:

Ancient Development

The camera as a device is a relatively recent innovation. However, the concept of the "camera obscura phenomenon" was recorded in China as early as 2674BCE in a text called the Nei-ching[8]. The book, now used as the basis of classical Chinese medicine[8], describes a box with a pinhole, a precursor to the most basic camera. Later, between 470-391BCE, the famous Chinese philosopher Mot-tzu described this box in more detail calling it "the locked treasure room" also translated as "the collecting place"[8]. His account includes all the basic principles of the camera, a dark box with a pinhole that could transmit a lighted image from one side to the other.

Mid 1800s

Although the camera was developed through the ages as a stand-alone device, it was not utilized in combination with endoscopy until 1858 when Johann Czermak incorporated the two[7]. Czermak was the very first to "take a photograph endoscopically" a practice later dubbed "stereoscopic photography"[7]. No one else had met the challenge of applying photography to minimally invasive surgery[7], perhaps because cameras were not yet commonplace. Lack of popularity meant lack of patients Czermak could test his device on so he performed "experiments on himself" and ended up photographing "his own larynx"[7]. His camera device was a simple box that contained multiple lenses arranged in such a way to capture the illuminated subject as an image onto "metal plates coated with silver nitrate"[7]. Surprisingly, Czermak's light source was a simple candle that was magnified to increase its illumination[7]. Although the images Czermak's camera produced were of poor quality by today's expectations they opened the door to a new type of surgery that relied on “photodocumentation”[7]. Being able to photograph surgical procedures as they were happening allowed other physicians, who were not present in the room, to learn from them as if they had been watching the surgery themselves[7]. Higher visual understanding with photography drove other surgeons to make visualization even better eventually leading to “videoendoscopy”[7].

A few years after Czermak, the German Theodor Sigmund Stein was actually recognized for “establishing scientific photography in 1874”[15]. His name may be familiar for his gas magnesium lamp introduced in the illumination category. Stein was able to build an “automatic endocamera” also known as a “photoendoscope” that had more practical uses than Czermak’s device since it was automatic[15]. Stein himself called the camera device a “heliopiktor” and it has been called the “forerunner to Polaroid technology”[15].

Prior to video endoscopy only one person was able to view the body cavity in question at a time. That is until 1887 when accessories called “split arms” were being sold as training utensils[20]. These attachments split the viewing lens in two with a divider that allowed “assistant surgeons and the like” to view the body simultaneously with the surgeon[20]. Unfortunately splitting the image tended to reduce visibility as a whole since the illumination of that image was also cut in half. This training device would ultimately fall by the wayside and be replaced with video endoscopy at a later time[20].

Early 1900s

The 20th century saw the rise of endoscopes with “photographic powers”[18]. The new and improved scope, titled “stereo-cystoscopes”, were able to divide the source of light into two separate beams, “one beam for immediate viewing, and the other for photographic purposes”[18]. Recall Ringleb, known for righting the inverted image and contributing to illumination. He was also one of the first to adopt photographic scopes and push the boundaries in camera technology[18].

Photography continued to be slowly incorporated into scopes and used in a multitude of procedures. In 1934, the inventor Carl Schroeder was able to procure the first photographic image of the uterus by attaching his own camera design to a hysteroscope[13]. In 1937, the famed intern from Los Angeles known already for his “foreblique visual system” of lenses[19], was “one of the first to introduce ACMI photography to scopes by attaching a photographing unit to his new scope dubbed the peritoneoscope”[19].

The year 1938 was spectacular in the advancement of camera technology. It was in this year that German’s Hoff and Neelf worked as a team to introduce the color photograph for endoscopy[19]. The men used a “mirror reflex camera” to take photographs “during an endoscopic procedure”[19]. They used high quality materials of their day such as “kodachrome film”[19]. A few years later in 1941, cinematography became the new conversation piece when Brubaker and Holinger introduced their "magnesium flash bulb" that created sufficient light to allow for moving pictures[21]. In 1945 they demonstrated a bronchoscopy procedure to the medical world using video[21].

Mid 1900s

While these cameras and video cameras were still bulky and mostly impractical to use, the pioneers of endoscopy did not give up. In 1955, Raoul Palmer was one of these surgeons who adopted "film and photographic technologies" for his own procedures[21]. He gained the title of first to have performed a pelvic surgery live using color film to record a movie of his technique[21]. Unknown to him at the time, Palmer's invention of quartz rod lenses would go on to be incorporated into modern fiber optics[26]. Yet another video pioneer was Albert Decker, who was discussed above regarding his illumination contributions, also recorded a live endoscopic procedure, this time regarding gynecology[21]. The technique was called "cine culdoscopy" since Decker inserted his endoscope with a camera clamped to the proximal end into a "culdoscopic incision"[21].

Although video as a source of visualization was gaining ground, it was by no means popular among traditional surgeons. Most common surgeries performed daily still used open techniques or older endoscopes that did not have photographic capabilities. However, those who designed, developed, and adopted these camera and video technologies would be the first written in history as exceptional pioneers for their fields. One example is the Japanese team Mori and Yamadori who were able to record the birth of a human baby on film "using a glass fiber hysteroscope"[25]. Other innovators from Japan include Uji, Fukami, and Suginara in collaboration with the Hayashida Hospital. They designed and built a camera for the gastroscope called the "gastrocamera"[25]. As procedures and techniques evolved into separate fields specific to bodily regions, so too did the scopes and their attachments.

Another practitioner who promoted using cameras, videos, and television monitors was Melvin Cohen[26]. In 1953 he and his co-inventor Guteman developed a "motion picture system" that could be attached to endoscopes to be used during surgery[26]. They named this device the "Cameron cavicamera"[28] and its introduction into medical society was warmly received and "highly influential in multiple endoscopic fields"[26]. The recorded videos of these surgeons could be viewed later in the classroom for future training but the draw to truly live procedures took video one step further. In 1955 a French team of bronchoscopists including Soulas and Debois de Montreynaud not only performed a live procedure on the windpipe but also were the first to broadcast their technique on live television[25]. If their procedure could be broadcast to a television screen anywhere, why not broadcast inside the surgical room itself? This idea was tested in a few surgical centers in 1959 with closed circuit television[25] although it did not gain popularity until much later.

By the 1960s cameras were being used in the operating room to transmit images of the interior body to a television monitor. However, they were extremely bulky and the whole system weighed upward of 80kg or 176lbs[29]. Seeing potential in video's ability, Dr. George Berci from Los Angeles wrote an article to describe the benefits of using television with endoscopy, "including the capability of viewing the images immediately, enlarging and recording them, correcting them for brightness and contrast, and allowing multiple observers access to the images"[29]. Yet, despite his promotion of the technology, Berci realized that cameras were still too massive to be used practically[29]. In 1962, Berci decided to jump this hurtle by designing his own camera, one that was much smaller and far lighter[29]. His miniaturized camera weighed in at 0.35kg, or 0.77lbs, a feat that far outweighed its predecessors in usefulness[29]. His camera could be coupled to the endoscope with no additional attachments necessary[29]. Although the image of Berci's camera only recorded in black and white, the image was magnified further and could be stored on 16mm movie film[29].

While Berci's camera could only record black and white, film of the late 1960s showed improvements. When combined with a white xenon vapor light, color film could be utilized to its full potential providing real to life images of the body's interior[13]. One product advertised in this era was the "Lumina system" that included the xenon light, "color film with appropriate speed" and better optics[13]. This is one of many products that began to be mass-produced and advertised to physicians rather than the custom scopes designed for a singular procedure of the past.

The Modern Age of Video

The 1970s showed a real shift in surgical technique "away from open surgery and into the realm of operative video [scopes]"[28]. Video endoscopy truly encompassed all aspects of what a minimally invasive philosophy had intended[28]. The next step was to simply utilize the technology more. Camran Nezhat, a surgeon specializing in gyneocology, did just that[29]. Nezhat recalls, "I started borrowing cameras that were used for microsurgery to see if I could rig it so that the procedure was displayed on a monitor"[29]. By the late 1970s Nezhat started using a television screen in the surgery room as his main source of visualization for the procedure, a process called "operating off the monitor"[28]. While operating to cure the complex disease endometriosis in a patient, Nezhat realized that if this disease could be managed using scopes then nearly all others, no matter their location in the body, could be treated similarly[28]. This realization opened his eyes to the real possibilities that are performed by endoscopy today.

Previously, endoscopic procedures were performed using an eyepiece as the only mode of visualization, which required the surgeon to bend over and look through the lens[28]. Endoscopic surgeon Dr. Rick York recalls, "These older instruments were a hollow tube with a magnifying lens and you can imagine that a pipe can only give you a limited range of view…along with a limited range of motion because these rigid scopes can only be manipulated so far before you come to a bend [within the body] and the scope starts causing damage"[30]. Further drawbacks of this method included lower back pain for the surgeon and poor visibility of the abdomen because only one eye is used causing lack of depth[28]. By operating “off the monitor” as Nezhat suggested the surgeon was able to look at the larger image projected on the screen and perform procedures while standing upright reducing both back pain and eyestrain that occurred with traditional eyepiece endoscopes[28]. This was a dramatic change in visibility as Dr. Rick York remembers, “On the screen, the image is larger than life and the detail [of the picture] is much greater [than before]. We could now look at an HD TV.”[30] Since the monitor was out in the open, the surgeon had a better view of the video image and so did the rest of the operating room staff[29]. Having multiple people view the surgery at once allowed the operative staff to synchronize their actions with that of the surgeon[29].

Operation by video monitor allowed minimally invasive surgery to “be set free from hundreds of years of history of peering directly through a tube, specula, or scope”[28]. However, traditional endoscopy was not completely eliminated. The early years of video endoscopy, prior to digitalization, were possible by only a small degree because the images transmitted did not have nearly the high resolution we have today[28]. In fact, the images were quite grainy and detail was not easily distinguished from television static[28]. This was primarily because light quality of the Hopkins’ lens and fiber optics, while considered high quality for the time, was still unable to be separated into distinct, yet still high quality streams to be directed to the screen[28]. While Nezhat and other surgeons like Dr. Phillip Mouret, Dr. Barry McKernan, and Dr. William Saye still practiced the “off the monitor” technique, many of their peers were still not convinced of the idea because they said, “it was quite disorienting to view barely discernible images emanating from a low-resolution, two-dimensional screen positioned several feet away from both surgeon and patient.”[28]

Although there was still much to be desired by using video endoscopy, it did offer a promising future. Visualization of surgeries offered something textbook studies of endoscopy could not, the ability to act as a “common language” for practitioners no matter what their native tongue[29]. These videos were recorded and sent as learning tools to explain with real world visualizations how a procedure could be performed and ultimately progress surgical technique[29]. Dr. McKernan, one of the surgeons who followed Nezhat in performing “off the monitor” procedures, recalls, “Once we had the VCR [video cassette recorder], we could make video tapes, and it was like night and day… I recorded all my procedures [so that] observers could actually see these operations were possible.”[29]

The Modern Age of Miniaturization

From the commercial perspective, color film for video endoscopy became available in 1972[13]. This setup included fiber optics that would transmit a “microscopic image to an 18lb, three-tube video camera”[13]. More often than not this system was used for teaching purposes, because it made multi-viewing possible, rather than actual surgical procedures, since the 18 lb product was still considered too bulky[13]. One year later a 4lb camera was available on the market that could actually be connected directly to the scope[13]. This direct attachment did not require a fiber optic “image guide" to transmit the image through a connecting tube, unlike its 18lb father device which did[13]. Smaller and lighter, the camera was easy to work with and still provided a high quality image output[13].

True miniaturization became available for purchase in 1975, offering a camera that was only "2x2x8 in and weighing but 1lb"[13]. Like its 4lb predecessor, it increased mobility for the surgeon yet kept its high performance[13]. The market of the 1980s offered a camera that could fit "in the palm of the hand" and its weight was measured in ounces but did not diminish performance as it included a "full range of natural color with excellent resolution"[13]. Today the market is abound with various cameras, some of which are "less than 2in on a side and weigh less than 3oz"[13] thanks to the introduction of solid-state computer chips to video endoscopy in 1982[6]. Most of these modern cameras are waterproof, although some are still only water resistant, so that they may be "soaked in liquid disinfectants" without damaging the internal components[13].

The next step in camera technology is continual improvements of the computer components inside. One such example is the change from 1-chip computer components to a 3-chip design. William Chang, in collaboration with Stryker, was the first to take existing 3-chip technology and repurpose it for endoscopic video cameras in 1989[31]. Like so many pioneers before him, the ideas and technology existed but had not yet been applied to minimally invasive surgery. While cameras with one computer chip produced visible results it could only interpolate mathematically to determine what the data would be between pixels[31]. The 3-chip, however, used three separate sensors, red, green, and blue, to accurately absorb all the body's colors at once[31]. Three-color sensors creates a higher spatial and color resolution along with greater sensitivity[31]. Chang recalls, when the "general surgeon [was] able to visualize tissue colors vividly, the key-hole surgery was as good as open surgery" with the added advantage of shorter recovery times that Change says "was huge" for the patient[32]. What made Chang's design stand out from the crowd was that this camera could be fully soaked in order to be properly disinfected[31].

Accessibility

The advancements of visibility were indeed remarkable but could not have been developed with out some sort of access into the body. Many of the first minimally invasive techniques entered the body only through natural holes or orifices such as the mouth, ear canals, nasal cavity, and vaginal and rectal openings. Granted, physicians could only view complications of the body through these natural ports if they affected these areas of the body. The next natural step was therefore what is considered "traditional open surgery", a procedure that is "associated with large incisions and extensive patient trauma"[3]. While it is known, based upon the setbacks faced by endoscopy's pioneers, that this traditional open surgery was the standard practice for thousands of years, the concept of minimal invasion according to Hippocrates II persisted and helped form what is currently known as endoscopy today. Due to this persisting idea surgeons took the next leap in accessing the internal body cavity and began cutting “small ‘keyhole’ incisions” through which a scope could enter[3]. To accomplish this more modern accessing technique tools such as trocars, insufflators, and even tubing evolved.

<u>Orifices:</u>

Ancient Development

Orifices are the entrances and exits of the body. Unless a person is cut, bacteria and disease enter through these holes causing infection. However, scopes may also enter through these holes to help the physician assess the situation with the intent of curing it. The entrance method of scopes of the orifice was used for thousands of years. Some of the oldest pioneers of visibility, discussed in the prior section, used the orifice to explore the body. The Egyptians are often cited as being one of the first cultures to perform endoscopic techniques, recalling the *Edwin Smith Papyrus* from 1700-1600BCE that references 2640BCE[8], who would presumably have used the openings such as nasal passages to view at least partially the internal body. Recall that other ancient cultures used similar techniques such as the Arab-Spanish physician Abulkasim who used reflected light to view the cervix through the vaginal orifice[6] along with the ear[8] during his lifetime between 912 and 1013 CE[6].

Speculums, tools comprised of two to three flat panels that open and close by means of pressure or crank[23], were the precursors to endoscopes since they allowed physicians to access and then visualize with sunlight various open cavities in the body. Prototype speculum that opened certain orifices such as the vaginal canal or the rectum were used to view these internal passages as early as 500BCE according to the *Ayurveda of Susruta* in India[23]. The next known description of obtaining visualization of the rectum was in 400BCE by the well-known advocate of minimal invasion as a principle of medicine Hippocrates II[8]. In his work *The Art of Medicine* he explains how hemorrhoids may be viewed and provides a detailed account of how this examination through our natural orifices could be replicated[8]. Actual remnants of speculums were discovered in the ruined city of Pompeii that date as far back as 76 CE, suggesting that this culture was seeking knowledge of the internal body as well[23].

Early Development

History jumps forward a thousand years or so to find a few other mentionable discoveries in regard to accessing the body through orifices. The first detailed description of the nasal cavity using a speculum to aid him was by Guy Chaulic in the 13th century[23]. Arcolano eventually illustrated his description in various texts in the following century[23]. It was not until lenses and optics advanced enough to actually visualize these open bodily cavities better beyond the naked eye that these orifices could be explored in greater detail. A precursor to advanced lenses, however, was focusing candlelight using a water filled glass bulb[23]. Recall that it was Arranzi who first employed this method in the 15th century to look at the interior nasal cavity[23].

Modern Development

The natural opening into the body, the humble orifice, was not forgotten in endoscopy's history. It is still used today to diagnose and treat conditions. Even when technique and antibacterial solutions allowed for safer incisions, many physicians preferred convenient body canals to test their newest endoscopic invention. A few of these notable surgical pioneers who continued to use orifices as their mode of access were British army surgeon Archibald Cleland who, in 1729, used biconvex lenses to view the nose[10], Bozzini in 1805 who observed the rectum and believed his scope design could have many applications within the body[11], and Desormeaux who also looked into the rectum using what can be considered the first "effective endoscope" in 1843[6].

The body's open cavities were an appropriate doorway to understanding what lies inside and therefore helped the curious develop endoscopic tools with which to view them. However, it only revealed a very small area of the body meaning only these few visible areas of disease could be diagnosed and treated. It was not until incisions could be made safely that exploration of the interior abdomen was possible.

Trocar:

How They Work

Both open surgery and minimally invasive surgery today involve incisions (that is unless the affected area is inside an orifice). Minimally invasive surgery, however, uses a significantly smaller incision. When an endoscope is placed through the incision the skin and protective tissues can be damaged because as the scope moves about, these fragile tissues can rip and tear apart causing scar tissue. The solution to this problem is the trocar. A trocar is a hollow, rigid tube that is inserted through the incision and acts as a "working channel" between the outside of the body and the interior cavity[4]. Scopes and other devices like small cutters or staplers can slide through this hollow tube and have mobility without damaging the surrounding skin and connective tissue[4]. Modern trocars also act as airtight seals so that the pressurized gas used for insufflating the body cavity does not escape[4].

Ancient Development

Trocars have been around since ancient times but not in the same way incision placed trocars are used today. One of the earliest known records of trocars was in the texts of Abulkasim (or Abu-al-Qasim depending on the Arabic translation of his name) called *Al-Tasrif* or *The Method* from 936 to 1013 CE[8]. In his encyclopedia he talks of a device used in surgery that had a handle attached to an “exploring needle with a groove”[8]. It is not certain if this trocar was used to drain disease on a physical level or a spiritual one, but the process to cure ailments using this device was described in detail.

Another example of trocar use in history was by the Roman doctor Aulus Celsus in 25 BCE to 50CE who wrote in his medical journals of a surgical procedure to restore “balance” in the body[8]. This process, now considered “quasi-surgical”, involved “inserting a trocar-like instrument into the abdominal cavity in order to drain disease causing, bad humors”[8]. Celsus’ description can be interpreted as similar to modern acupuncture since its intent is to release the bad auras that were blamed for causing disease and infection in his day[8]. His texts detail the trocar device and technique stating, “A leaden or copper cannula with its lips curved outwards, or one that has a circular rim at its middle to prevent its slipping into the cavity, is then introduced through the aperture [or incision]. When the latter is used, that part of the instrument that is introduced should be no longer than that which remains external to the aperture, in order that it may proceed beyond the peritoneum [also known as the abdominal cavity].”[8]

Early Development

Other cultures have written descriptions of rigid or semi-rigid tubes used in surgery to act as an exit for both spiritual and physical disease. While some texts are vague in their description, others talk of techniques to drain the bladder and “correct bladder location”[10]. These devices acted similar to modern trocars and can certainly be considered precursors. However, they were often clogged with bladder stones or other tissue, which lead to complications not only during the procedure but also for infection later[10]. Despite these problems, trocar-like devices certainly existed in antiquity. Yet, they were never called trocars but rather channels, canals, or simply drainage devices. It was not until 1706 when the expression “trocar” was first used[10]. The term originated from the French word “trochartor triose-quarts” that was used to describe “a three-faced instrument consisting of a perforator enclosed in a metal cannula [or a smaller version of the trocar].”[10]

To combat the ancients’ clog-able design, Domenico Masotti from Florence, Italy decided to design a new trocar[10]. In 1756 he developed a trocar with small canals on the sides to help drain any fluids even if the main channel had become blocked with tissue[10]. Masotti’s design was simple yet revolutionary and was used by the medical field for 200 years[10]. Although the issue of fluid flow was solved for the trocar, another problem took its place. Since the 1700s and well into the 1900s trocars still caused injuries themselves due to improper placement[18]. Whether the trocar design incorporated a blunt or sharpened tip (used to pierce through the skin), both could cause damage to internal organs and tissue if inserted too forcefully.

1900s

Trocars used in the modern method, insertion through an incision to act as a channel for devices rather than drainage was a relatively new concept in the 20th century. So new in fact that German surgeon Georg Kelling was the first in the medical field to use a "second trocar insertion"[18]. In 1901 when most surgeons used one trocar to insert endoscopes for diagnosis, Kelling placed two trocars in the abdomen[18]. His intent was to use one channel for visualization of the dark interior and the second to insert tools with which he could manipulate and cut the tissue in question[18]. This second opening was only possible in combination with his improvements to insufflation, discussed in the next section. With these two advancements in accessibility, Kelling was able to perform biopsies without "damaging any of the internal organs"[18]. Although double or even triple trocar entry sites are common today, it would take many more years for Kelling's insight to be accepted for common use.

Although a simple device, trocars were difficult to insert. Some of the original trocars were inserted only after an incision with a knife had been made. Later designs like Kelling's used the puncture method, which proved hazardous to internal organs despite the additional space made by expanding the abdomen by means of insufflation. A medical intern studying in Chicago named B.H. Orndoff saw these setbacks and decided to improve on the device[33]. In 1920 he developed a "sharp pyramidal trocar point" much like a sharpened pencil is shaped that helped aid the physician in puncturing the skin and connective tissues[33]. Orndoff also saw that while these trocar canals allowed the surgeon access to the interior, it also allowed the insufflation gas access to the exterior[13]. In order to prevent this gas from escaping the abdominal cavity, Orndoff invented an "automatic trocar-sheath valve"[13]. Similar to modern gas seals, it automatically closed the channel from the outside using a metal panel.

Like all parts of the endoscope, trocars continually evolved through time even if the advancement was small. Among the pioneers to take trocars one step closer to the modern design was the German surgeon Heinz Kalk[19]. Using Kelling's technique of two trocars to increase accessibility to the internal body, Kalk founded what is considered the "dual trocar approach"[19]. While he did not invent the idea (Kelling did), Kalk was the first to apply it regularly during surgical procedures[19]. He also made a few minor adjustments to its design that allowed it to be used more safely[19].

The Modern Age

Trocars are a simple yet necessary part of endoscopy to access the interior body. Not much design change was necessary to allow them to function like modern market trocars. Yet, in 1987 the USSC (the United States Surgical Corporation) designed a trocar called the SurgiPort that would revolutionize the operative field, it was disposable[29]. Disposable devices meant increased safety to patients because there was no risk of infection and to the safety of the internal organs because the device would perform exactly as it was designed every time. The blade would never dull and spring loaded puncturing would never break because this trocar would only be used once. USSC also added a safety shield that could “cover the trocar tip to protect the underlying abdominal organs”[29]. This additional attachment to the trocar was an amazing improvement because it eliminated the risk of organ damage from initial puncture. Dr. Frederick Greene from Carolinas Medical Center in Charlotte, North Carolina recalls, “these trocars were safer because surgeons could watch the trocar as it entered the abdomen and avoid piercing any organs accidentally”[29]. Other products of similar design are currently on the market as well but the USSC remains well known for being the first to market such a transformative instrument.

Insufflation:

How It Works

Insufflation is a relatively new concept compared to the ancient developments in optics, illumination, and trocars. Prior to its development, surgeons entered the body through an orifice that could be or was already expanded naturally like the mouth, nose, or rectum. However, insufflation changed the way minimally invasive surgery could be performed. Insufflation is the process where space is made in the abdominal cavity by filling it with an inert gas, often CO_2 [4]. Once the abdomen is inflated the new workspace is called the “pneumoperitoneum”[4]. It should be noted that CO_2 is the gas of choice today because it “has the advantages that it can be adsorbed by tissues in the body and removed by the respiratory system, and that it is nonflammable”[4]. Filling the body with gas to create a working space is necessary because without it scopes would not have visualization of the interior and the instruments could cause harm to the internal organs[4].

Early Development

The earliest known example of insufflation was between 1493-1541 by the Swiss physician Theophrastus Philippus Aureolus Bombastus von Hohenheim also known as Paracelsus[9]. It was difficult both visually and mechanically to perform biopsies on the interior of the body without causing harm to the patient’s organs[4]. To combat this issue, Paracelsus designed a technique to expand “the lungs of his suffocating patient by devising a clever system using bellows to blow air into a tube that was placed in the mouth”[9]. The bellow and tube design worked for Paracelsus’ purpose but did not gain much attention in the medical community. It would be hundreds of years for this idea to be explored again.

1800s

For a long time insufflation was used for curative properties, not surgery. The earliest recorded account of a peritoneum in a human was in 1882 by Albert von

Mosetig-Moorhof[18]. He is credited with using insufflation to cure “a 4-year old boy infected with TB [tuberculosis]”[18]. Establishing a sealed peritoneum during this era was difficult. For this reason other surgeons utilized a technique known as “natural insufflation”[18]. Natural insufflation involves “positioning female patients in the deep Trendelenberg” or a position of wide spread hips raised in the air above the head so that air is sucked into the pelvic area of the body[18]. This position worked well on females but the method could not be translated to male patients due to differences in anatomy. Therefore, to serve both sexes, artificial insufflation was necessary.

Early 1900s

The concept of inflating the abdomen was not a new one since Von Mosetig-Moorhof already accomplished it along with other physicians[18]. However, the first pioneer in modern artificial insufflation was German surgeon Georg Kelling. Already recognized previously for his double entry trocar, Kelling designed an insufflating device that filled the abdomen with filtered air[18]. He used this device along with Nitze’s child sized scope to establish a peritoneum and perform one of the first “successful endoscopic procedure[s] within the abdominal cavity of a living dog”[18]. This procedure was performed live in front of the 73rd Congress of the Naturalist Scientist’s Medical Conference in 1901[18]. Kelling was also the first to successfully insufflate and perform surgery on humans between 1901 and 1923[18]. Kelling said his drive to develop insufflation was to prevent the “damaging of any internal organs”. He was on the cutting edge of minimal invasion because he understood that insufflation would increase the safety of endoscopic surgery; it allowed trocars and scopes to safely enter the body[18].

While Kelling suggested insufflation was a means of greater visibility, accessibility, and safety, he did not realize the consequences it came with. It was not understood in the mid 1800s that “too much insufflation could have fatal consequences”[18]. Many of Kelling’s surgical procedures that utilized insufflation were successful but others were not. Due to its complications, artificial insufflation was not the method of choice but rather natural insufflation. A strong advocate for the natural method, preferring to cause as minimal harm to the body as possible, was Dimitry Otto from St. Petersburg[18]. In 1901 he was the first to implement the “Trendelenburg position” for use in endoscopic surgery[18]. To keep the abdomen distended Otto inserted a cotton filter into the vagina of a patient in the Trendelenburg position so that the body would naturally “vacuum the filtered air into the abdominal cavity” and keep the air inside until the filter was removed[18]. To keep his patients in this awkward position, Otto attached raised stirrups and shoulder-holders to the operating table[18].

In 1920, another step toward advancing insufflation came to light. B.H. Ordnoff, the same intern from Chicago who designed the pyramid shaped trocar to aid puncturing the abdomen, attempted to solve Kelling’s safety concerns[33]. Initially Ordenoff used CO_2 in his endoscopic procedures[33]. However, he soon acknowledged the complications involved regarding CO_2 gas and atmospheric air after suffering the loss of patients from an “air embolism associated with carbon dioxide insufflation[33].

Therefore, Ordnoff decided to change his insufflation gas to oxygen[33]. However, pure oxygen is a much less stable gas than carbon dioxide. While it is not known if Ordnoff encountered complications with this gas, it would cause problems for future pioneers.

In the beginning of the 20th century a wide variety of insufflation techniques were used side-by-side. Swiss surgeon Richard Zollikofer preferred artificial insufflation and CO_2 as the gas[20]. He understood and explained the advantages of carbon dioxide to establish the pneumoperitoneum and introduced his idea to the medical community in 1924[20]. In 1930, American surgeon Carl Fervers came to the same agreement as Zollikofer. Fervers previously used atmospheric air for insufflation in endoscopic procedures, but he began noticing “audible explosions and flashes of light”, a phenomenon produced by the mixture of his electro-cautery tools and the oxygen in the air[19]. The combination of electricity and oxygen was a real fire hazard and safety concern for the patient’s delicate organs.

Regardless of which type of gas was used to perform insufflation, surgeons were having a difficult time preventing the gas from escaping the abdomen. That changed when, in 1937, Janos Veress, a surgeon from Hungary, designed a special valve needle[19]. He initially invented this needle to help treat tuberculosis but soon noticed that it could be used to establish a steady pneumoperitoneum safely[19]. Varess’ design consisted of a hollow needle, much like a miniature trocar, that had a “spring-loaded obturator” or valve that could open and close upon command[19]. The valve allowed the needle to be safely inserted into the abdomen and created an airtight seal of the distended cavity[19]. This needle design in combination with CO_2 created a safe technique for insufflation[13]. Verness’ needle is still used today with only minor changes made to it throughout the years[19].

Mid 1900s

By now, surgeons could establish and maintain a pneumoperitoneum but they had no way of monitoring it. Since there was no way to monitor the amount of air that was entering the abdomen “many patients were dying from air embolism”[21] or small bubbles of air that had been introduced to the blood stream causing a stroke and consequently death. Raoul Palmer, a gynecological surgeon, became aware of this problem after complications with his own patients[21]. In 1947, Palmer was the first to propose monitoring the insufflation gas[21]. In the name of safety, Palmer stated that the maximum pressure the human abdomen could sustain without complication was 25mm Hg [21]. Furthermore, this pressure should be established at a filling speed of no more than 400-500cc per minute[21]. This pressure, he said, should be “continuously maintained and monitored throughout the entire procedure”[21]. Palmer’s standard of maximum filling rate and pressure is one that is still used today[21].

Palmer was also part of the majority shift from atmospheric gas toward CO_2 gas for insufflation as was Hans Frangenheim[21]. Already known for his early implementation of quartz rods and later on fiber optics, Frangenheim adopted CO_2 gas for insufflation as well[21]. In 1950 he also built his own improved insufflator design to accommodate CO_2 gas[25]. By the mid 20th century carbon dioxide became standard as the gas of choice for insufflation.

The Modern Age

The next great development in insufflation appeared in 1966 with Dr. Kurt Semm[26]. A German surgeon, Semm took Palmer's monitoring suggestion for safety to heart[29]. He designed what is known as the "automatic insufflator", which could "inflate the abdomen with carbon dioxide (CO_2) gas while monitoring intra-abdominal pressure"[29]. This was a great leap from simply measuring the pressure by hand throughout the procedure. Semm's design, dubbed the "CO_2-pneu machine"[26], had the ability to fill the abdominal cavity with carbon dioxide to the appropriate pressure and observe the pressure was maintained[29]. This was all accomplished electronically and with a high degree of precision[26]. Great precision in measurement translated to reduced risk and therefore safer outcomes for the patient, which is the ultimate goal of minimally invasive surgery.

Tubing:

Ancient Development

Tubes are perhaps the simplest component that comprises the endoscope. As a stand-alone object, tubes are some of the oldest artifacts found and can be made of wood, metal, or bone. They are as old as endoscopy itself and the first portion of endoscopic accessibility, in combination with orifices, to be applied. The first endoscopes to house lenses were encased in a rigid metal tube. The history of endoscopy took this rigid metal tube and manipulated it to house new optics and illumination. As the mechanisms of visibility changed and improved from glass lenses to fiber optics, and from ocular viewing to cameras, so too did the tube change.

1800s

Previously known for his advancements in illumination, Pierre Salmon Segalas took the first step in changing the basic metal tube design[12]. In the early 1800s, Segalas changed the tip of his scope from a rigid metal to a "gum elastic material"[12]. This simple design change greatly improved safety and comfort for the patient because its flexible design did not cause damage to any fragile bladder tissue[12]. In Germany, a few years later, Adolf Kussmaul also desired improved access into the body[7]. In 1868, he enlisted the help of a professional sword-swallower in the hopes of learning how to navigate "through the body's most treacherous contours"[7]. Using Desormeaux's gasogene lamp for illumination, Kussmaul invented a custom "47mm long and 13mm in diameter tubing with speculum"[7]. With this tube and his knowledge of the sword-swallower's esophagus, Kussmaul was able to reach the stomach through his patient's mouth[7].

Despite these small changes, tubes remained relatively the same rigid metal design for a long time. Often the only changes in design would come from inventors' customizing the tube for their desired procedure, an example of which were Mikulicz and Leiter, in 1881[7]. Their names should be familiar since they were already well known for improved optics and a water-cooled, electric heated galvanized wire light bulb[7]. Their surgical technique required what is called a "guiding mandarin", which is a pointed metal tip inserted in the tube to help manipulate internal organs[7]. To accommodate the new lenses they designed along with this mandarin, the tube of their scope would have to be a wider diameter[7]. However, the larger the diameter of tube, the more invasive the surgery becomes. Therefore, they designed their tube to have segmented parts so that after inserting the scope into the body, the guiding mandarin could be removed "thereby allowing room for the optical apparatus to then be inserted"[7]. This open and removable design allowed Mikulicz and Leiter's scope to keep a smaller diameter[7].

Once Mikulicz and Leiter introduced their "sectional" tube design, other inventions began to appear[18]. Motivated by his predessors, Kelling, the same great innovator of insufflation, developed his own tube design in 1897[18]. His tube mirrored the movement of a finger in that it was "constructed of vertebrate segments of hollow tubes"[18]. Each of these sections was then coated with Indian rubber to ease its mobility and prevent tissue from becoming trapped in the creases[18]. Just like a human finger, the tip of Kelling's scope "could be angulated or pulled straight" by a "system of wires which were controlled proximally"[18]. This multi-flexible tube design was more effective for accessing all areas of the body. While some of Kelling's peers called his flexible scope "clumsy", others in the field touted it as a "masterpiece of optics and mechanics"[18]. Regardless of his peer's opinions, Kelling was on the cusp of innovation for his day[18]. Today, flexible scopes are the instrument of choice for minimally invasive procedures that require more mobility.

As other components of the endoscope evolved, so too did the tube. Recall from the camera section in visibility that the first camera used in endoscopy was in 1858 thanks to Czermak's innovation[7]. It took forty more years for the tube attached to that camera to become flexible. In 1898, the two doctors, Lange and Meltzing, designed a flexible tube that could be attached to a camera[20]. Thanks to its great mobility, their scope could bend past the contours of the esophagus and allow visualization of the stomach[20]. What made this design remarkable was its ability to take multiple photos[20]. To capture these photos while still maintaining flexibility the image was reflected by various optical pieces along the tube, an amazing accomplishment prior to the invention of fiber optics.

The Modern Age

By the early 20th century both rigid and flexible scopes were being used. Another pioneer seeking improvement on tube design was Dr. Rudolf Schindler[34]. Early in his career he designed custom “rigid optical gastroscope[s]” for use in diagnosis and treatment of the stomach[34]. However, like Kelling before him Schindler recognized the “great hazards associated with the use of the rigid” scope[34]. In 1924, fueled by the desire for patient safety, Schindler designed a totally flexible scope[34]. After five separate model changes he finally settled on a semi-flexible scope, which would eventually go on to be the standard scope design used in gastrointestinal endoscopic procedures[34]. The semi-flexible scope was then manufactured and marketed by the Wolf Company and boasted features like, “48 lenses” in order to aid in illuminating the stomach, and a soft tube that “decreased the risk of perforations”[19]. Schindler’s semi-flexible tube remains on the market today with only minor alterations to its design.

Ethics

Modern endoscopy and laparoscopy procedures are riddled with ethical questions. Many ask if certain minimally invasive procedures should be performed at all. Others question what defines appropriate safety standards for minimally invasive procedures such as age or predetermined conditions like heart palpitations making risky and unwelcome candidates for procedures under anesthesia. However, since these questions all revolve around the main axis of procedural techniques, they will not be analyzed for the purposes of this paper. The main focus of this text being the evolution and advancement of the endoscopic instrument in a physical sense, the ethical question posed here is: Should society have been using and advocating the technology as it progressed? It is true that the only way progression can occur is through trial and error but would it have been considered too risky to use humans as trial guinea pigs when the technology was not quite so advanced and mortality rates high? Many critics seemed to think so and their social stigma caused by the advocacy against minimally invasive techniques throughout history often times held advancements back.

Minimally Invasive vs. Open Surgery

First, it is advantageous to discuss the reasons that endoscopy can be beneficial for both the patient and physician. Nurse Kay Ball explores these benefits suggesting, “Patient selection criteria have been broadened to include those who normally would not qualify for an open procedure (e.g. people with diabetes, pregnant women, debilitated patients).”[2] Furthermore, minimal invasion reduces the amount of blood loss during surgical procedures compared to open techniques[2]. Due to a smaller incision, endoscopic surgery results in “less postoperative pain” and also “fewer postoperative infections”, which is vital for high-risk patients like diabetics or those who are immunocompromised[2]. Reduced trauma in surgery translates to reduced recovery time after surgery so that patients can return to daily life quicker[2].

Ball also offers a study that exhibited reduced recurrence of the complication in question since “the open approach for hernia repair was associated with a 10% failure rate, whereas the laparoscopic approach was associated with a failure rate of only 4%"[2]. Also, "endoscopy provides excellent exposure and visibility of different structures and organs for diagnostic and operative interventions" that are often better than the visibility available in open procedures[2]. This is perhaps the greatest benefit for the surgeon because it allows them to view the body in its entirety, and therefore, perform the procedure to the best of their abilities.

However in contrast, open surgical procedures also have their own advantages. Some can only be performed openly such as hip replacements due to the size of the implant. Similarly, large incisions must be made to remove sizeable masses such as tumors. Other procedures require manipulation of heavy organs or tissues that cannot be lifted by small endoscopic instruments. In other situations, where insufflation is not possible, a surgeon must open the body cavity in order to gain a sizeable workspace. Regardless of the situation there is certainly still a need for traditional open surgery. Although endoscopy seeks to replace most open procedures with minimally invasive procedures, the technology does not permit this transfer in all cases at this time.

Case Study

The 20th century saw the firm establishment of endoscopic surgery by pioneers who recorded their experiences with these minimally invasive scopes. One pioneer was Kelling, a surgeon who, driven by the desire for safety, developed the flexible endoscopic tube shaped like a finger[18] in 1901[13]. With this device he operated first on a dog and later on human patients[13]. However, in order to perform his operations, Kelling required a working space in the abdomen and therefore artificially insufflated the body[18]. Unfortunately for some of his patients at that time, the medical community, Kelling included, did not understand the negative consequences that over-insufflation caused[18]. Kelling recorded the deaths of these unlucky patients, although an exact count is not agreed upon[18].

Consider both the patient's and Kelling's situation. Although minimally invasive surgical treatment in Kellings lifetime were limited to "biopsies, removal of loose bodies, and trimming of menisci"[13] these techniques could still cure particular ailments. Was it appropriate for Kelling to have operated on a living dog? Perhaps the critic's opinion will change when asked the same of operation on a living human. Although neither Kelling nor the rest of the medical community were aware of the dangers of over-insufflation, should Kelling have used such a new technology if he was unsure of the safety and outcome of the procedure? Kelling had good intentions as shown by his flexible, soft-rubber scope. Does his good intent excuse his actions? Finally, is it acceptable to sacrifice patients in the name of medicine so that endoscopy could evolve into the safe procedure it is today?

Twenty years later, Orndoff, like Kelling, made strides in the advancement of endoscopic safety. Aware of the complications involved in accessing the body through trocars, Ordnoff designed the "sharp pyramidal trocar point"[33]. Due to its sharp point, puncturing the abdomen required less force and, therefore, promoted safety because surgeons were less likely to over force the tool and hit vital organs. Orndoff, like Kelling, lost some patients to "air embolism associated with carbon dioxide insufflation"[33]. In 1921, these fatalities were recorded in his medical journal[33]. To try and solve this complication, Orndoff changed his gas from CO_2 to oxygen[33]. Oxygen would prove to cause its own fatal impacts later in history due to its high reactivity, but it is not known whether or not Orndoff experienced fatalities while using oxygen for insufflation.

Consider Orndoff's situation in regard to Kelling's. Orndoff made two major advancements toward endoscopic safety: the improved trocar and a change in insufflation gas. Since the trocar resulted in lower organ damage and, therefore, fewer possible injuries or fatalities, it is without doubt a positive step toward ethical endoscopic practice. However, despite Orndoff's new trocar, his attempt at discovering a better insufflation gas would mislead future surgeons who ended up using oxygen for insufflation in combination with "electro-cautery equipment" that created "audible explosions and flashes of light"[19] causing patients to suffer burns and death. Should Ordnoff have experimented with oxygen as an insufflation gas when he was unaware of its reactivity? Could he have prevented future fatalities?

Kelling and Orndoff were not the only physicians to have experimented with insufflation. In 1924, Steiner used atmospheric air to insufflate his patients[20]. Like his predecessors Steiner did not realize that his patients could die of stroke if insufflation pressure was too great. In a statement showing his lack of concern Steiner said, "At first we measured the quantity of air used, but we have found that this is unnecessary for the abdomen is not very sensitive to inflation and easily withstands the quantity of air necessary"[20]. Steiner's lack of understanding regarding insufflation complications is clear. Does his bold statement reveal insensitivity toward the subject or simply misunderstanding? Nearly the entire medical community in the 1920s would agree with Steiner. Is that suggestive of poor medical research in the community in that era or simply oversight? It would take a little more than 40 years for the problem to be solved by Semm's automatic insufflating machine of 1966[26]. Should patients have been told of the safety concerns of insufflation during this time frame? Should physicians have opted for open surgery in order to combat the risk of embolism?

Probing Questions

These questions and more should be asked not only of insufflation but the many other complications endoscopy faced throughout history. For example, should physicians have used candles as their illumination source in surgery, especially when they were aware of the fire hazard? Furthermore, should light bulbs that overheated and caused patient burns internally have been placed on the distal end of the scope, such as Decker's "cine culdoscopy" in 1950[21]? In fact, it was not until Palmer's "quartz rod lens" (1952)[21] and later Hopkins' "flexible fiber optic" (1970)[13] that cold light truly provided a safe illumination source. Without the candle and light bulb precursors, cold light could not have developed, but is it ethical to have caused so many deaths in endoscopy's history in the name of developing a safe light source?

The intent of minimal invasion was to create as little trauma to the body as possible. However, throughout history "rising death rates caused by endoscopic mishaps were", as Dr. Nezhat states, "an inextricable part of the medical landscape"[33]. Among these mishaps were, "deaths caused by unpredictable insufflation complications, burns caused by electro-cautery"[33], fire hazards from open or overheating lights, and ultimately lack of understanding regarding how the body reacts during surgery and throughout recovery. Death and even injury is a high cost to pay for anyone. It is not clear if patients were aware of the dangers involved in these procedures of the past. However, today patients are made aware of possible complications prior to surgery. Should endoscopy's pioneers, as great as they were, have been experimenting on uninformed patients? Today prior to any new medical device is used in surgery, these questions are asked. Strict regulations have been put in place to help prevent further death or injury due to lack of understanding or oversight.

Future Speculation

This text on the history of endoscopy has explored the evolution of the endoscope from ancient times until modern, even touching on current market products. The question now: What is the next evolutionary step for endoscopy? That depends on whom is ask. Clarice Powers suggested that, "futuristic surgical interventions will move from minimally invasive techniques to non-invasive techniques. Concepts such as virtual reality, virtual imaging, robotics, and remote surgical interventions may well be the norm in operating rooms of the next decade"[13]. From her viewpoint in 1990, Powers had the right idea. While virtual reality still lives in imagination, robotics have made their way into the operating room.

Current robotics on the market include "Zeus" originally designed by Computer Motion (which merged with Intuitive Surgical in 2003), and the "da Vinci" robot that is currently on the market by Intuitive Surgical[4]. During the operation, the surgeon "sits at a 'master' control console that allows the surgeon to manipulate robotic arms and view the abdominal cavity" via a TV monitor screen[4]. The robotic arms act as a "slave" to the physician as it holds both the "endoscope and detachable laparoscopic surgical tools"[4]. The intent of these robots is to provide increased "levels of dexterity and vision to anatomical structures that cannot be approached by the surgeon's fingers", while still allowing the surgeon total control[4]. These surgical robots also tout a reduced "impact and trauma to the tissue surrounding the surgical site"[4]. They have not yet been designed and programed to perform all minimally invasive procedures and therefore will not be replacing the surgeon any time soon.

Martin Culjat et al. have a similar vision to Powers of the future of endoscopy. They foresee an increased "level of automation and control of the surgeon over the execution of the surgical procedure"[4], an aspect preliminarily seen in the da Vinci technology. While this is currently being used for hard tissue procedures, soft tissue procedures are still conducted under full human control, however this could change in the future. They also note that, currently, the “physiology and function [of the body] are not visually represented in conjunction with the anatomy [of the body]”[4]. This is an area visualization could improve upon by including the “physiology and function” of the body in the “anatomy” of the body by combining visualization techniques such as MRI, CT, or a yet undiscovered technology in conjunction with video cameras.

Kay Ball considers the modern complication of the loss of the “physician’s tactile sense” due to the fact that “tissue cannot be directly palpated” or handled[2]. Although the HD video used in endoscopy today helps combat this problem, “simulators are being designed to provide ways of actually feeling the tissue”[2]. These simulators would help build a total “virtual reality experience”[2]. Although far from achieving this goal yet, virtual reality could create a 3D environment that “mimics an actual endoscopic procedure”[2] to both help the student learn and the surgeon perform minimally invasive surgery. If simulations could be combined with current videoconferencing, Ball suggests that a surgeon would not need to be “at the patient’s side” but rather the procedure could be performed “at a remote site” with the physician “controlling the robotics that actually perform the procedure”, a technique called “telepresence surgery”[2].

These ideas create exciting visions of what the future could possibly hold. What is for certain is that endoscopy will continue to evolve in both visibility and accessibility. New pioneers will learn from their predecessor’s mistakes and advance the endoscope in such a way to make its visuals more realistic, the procedures safer, and reduce the overall trauma of surgery on the body. It is a thrilling time for endoscopy’s history. Current technology, like the robotic systems and fiber optics, are on the cusp of fulfilling Hippocrates minimally invasive philosophy, which is to create as little trauma for the body as possible while still treating the ailment.

Conclusion

Endoscopy is not a recent invention. In fact, it is quite ancient thanks in part to the minimally invasive philosophy that Hippocrates advocated in his lifetime. With his philosophy in mind, surgical pioneers went on to develop lenses, lighting, and cameras to aid in their search for visualization of the interior body cavity, along with trocars, insufflating machines, and tubing to help access it. The technology used in endoscopic procedures today was not just an advancement from early 20th century technology but rather a culmination of ideas and tools that took thousands of years to develop. It is with this understanding that the medical community is humbled by modern endoscopy. Furthermore, endoscopy’s extensive history teaches us to remain ever the vigilant student, seeking ways to continually better this branch of the medical field.

Certainly, it is true that endoscopy struggled in those thousands of years, but it was for the betterment of medicine. Ethical questions regarding past advancements help answer ethical questions of the present and future. While there may not be a correct answer, questions are intended to help open the reader's mind to discussions to be explored before new technologies are released into the operating room.

Citation:

1. Culjat, Martin, Rahul Singh, and Hua Lee. *Medical Devices Surgical and Image-guided Technologies*. Hoboken, N.J.: John Wiley & Sons, 2012. 277-286. Print.

2. Ball, Kay A. "The Evolution of Endoscopy." *Endoscopic Surgery*. Ed. Michael S. Ledbetter. St. Louis: Mosby, 1997. 1-14. Print.

3. Culjat, Martin, Rahul Singh, and Hua Lee. *Medical Devices Surgical and Image-guided Technologies*. Hoboken, N.J.: John Wiley & Sons, 2012. 3-9. Print.

4. Culjat, Martin, Rahul Singh, and Hua Lee. *Medical Devices Surgical and Image-guided Technologies*. Hoboken, N.J.: John Wiley & Sons, 2012. 29-96. Print.

5. Nezhat, Dr. Camran, and Barbara Page. "ENDOSCOPY AS A PHILOSOPHY." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_01/>.

6. Cunningham, Dr. Larry L, and Gilman P. Peterson. "Historical Development of Endoscopy." *Atlas of the Oral and Maxillofacial Surgery Clinics of North America* 11.2 (2003): 109-27. Print.

7. Nezhat, Dr. Camran, and Barbara Page. "THE LARYNX ILLUMINATED." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_10/>.

8. Nezhat, Dr. Camran, and Barbara Page. "ANCIENT TO PRE-MODERN PERIOD." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_02/>.

9. Nezhat, Dr. Camran, and Barbara Page. "RENAISSANCE, SCIENTIFIC REVOLUTION, AGE OF ENLIGHTENMENT." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_03/>.

10. Nezhat, Dr. Camran, and Barbara Page. "HOVERING ON THE BRINK OF MODERNITY." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_04/>.

11. Nezhat, Dr. Camran, and Barbara Page. "BOZZINI: THE BEGINNING OF EARLY MODERN ENDOSCOPY." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_06/>.

12. Nezhat, Dr. Camran, and Barbara Page. "POST-BOZZINI." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_07/>.

13. Powers, Clarice J. "A Brief History of Endoscopy." *Seminars in Perioperative Nursing* 2.3 (1993): 129-32. Print.

14. Nezhat, Dr. Camran, and Barbara Page. "DESORMEAUX." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_08/>.

15. Nezhat, Dr. Camran, and Barbara Page. "THE ERA OF NITZE." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_11/>.

16. Nezhat, Dr. Camran, and Barbara Page. "AFTER DESORMEAUX." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_09/>.

17. Nezhat, Dr. Camran, and Barbara Page. "ENDO-UROLOGY." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_15/>.

18. Nezhat, Dr. Camran, and Barbara Page. "EARLY 20TH CENTURY." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_12/>.

19. Nezhat, Dr. Camran, and Barbara Page. "THE GLORY DAYS PART II." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_16/>.

20. Nezhat, Dr. Camran, and Barbara Page. "THE GLORY DAYS OF ENDOSCOPY." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_13/>.

21. Nezhat, Dr. Camran, and Barbara Page. "1940'S." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_17/>.

22. Nezhat, Dr. Camran, and Barbara Page. "1970'S." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_20/>.

23. Rauchfuss, A. E. "[The Nasal Speculum. Its Historical Development and Remarks on the History of Rhinoscopy]." *Laryngologie, Rhinologie, Otologie* 64.11 (1985): 551-58. Print.

24. Ghirardini, G., and F. Golinelli. "Bozzini and the Birth of Endoscopy." *Clinical and Experimental Obstetrics & Gynecology* 19.1 (1992): 70-72. Print.

25. Nezhat, Dr. Camran, and Barbara Page. "1950'S." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_18/>.

26. Nezhat, Dr. Camran, and Barbara Page. "1960'S." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_19/>.

27. Corning. "Lesson in a Box." *Corning Optical Fiber*. Web. 16 Mar. 2015. <http://www.corning.com/opticalfiber/fiberbasics/lesson/index.aspx>.

28. Nezhat, Dr. Camran, and Barbara Page. " NEZHAT & THE RISE OF ADVANCED OPERATIVE VIDEO-LAPAROSCOPY." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_22/>.

29. Stern, Victoria. "Landmark Strides in Laparoscopic Technologies: Video to Robotics." *General Surgery News* 1 Oct. 2013. General Surgery News. Web. 16 Mar. 2015. <http://www.generalsurgerynews.com/ViewArticle.aspx?d=In the News&d_id=69&i=October 2013&i_id=999&a_id=24140&ses=ogst>.

30. York, Dr. Rick. Telephone interview. 9 Apr. 2015.

31. Feingold, Benjamin. "Interview of 3-chip." Personal interview. 9 Mar. 2015.

32. Chang, William. “Interview of 3-chip.” Electronic mail interview. 16 Apr. 2015.

33. Nezhat, Dr. Camran, and Barbara Page. "RECAP OF WHERE ENDOSCOPY STOOD." *'History of Endoscopy'* Ed. Dr. Paul Alan Wetter. Society of Laproendoscopic Surgeons, 1 Jan. 2005. Web. 16 Mar. 2015. <http://laparoscopy.blogs.com/endoscopyhistory/chapter_14/>.

34. Dagradi, A. E., and S. J. Stempien. "In Memoriam Dr. Rudolf Schindler." *Gastrointestinal Endoscopy* 15.2 (1968): 121-22. Print.